CHAPTER EIGHT

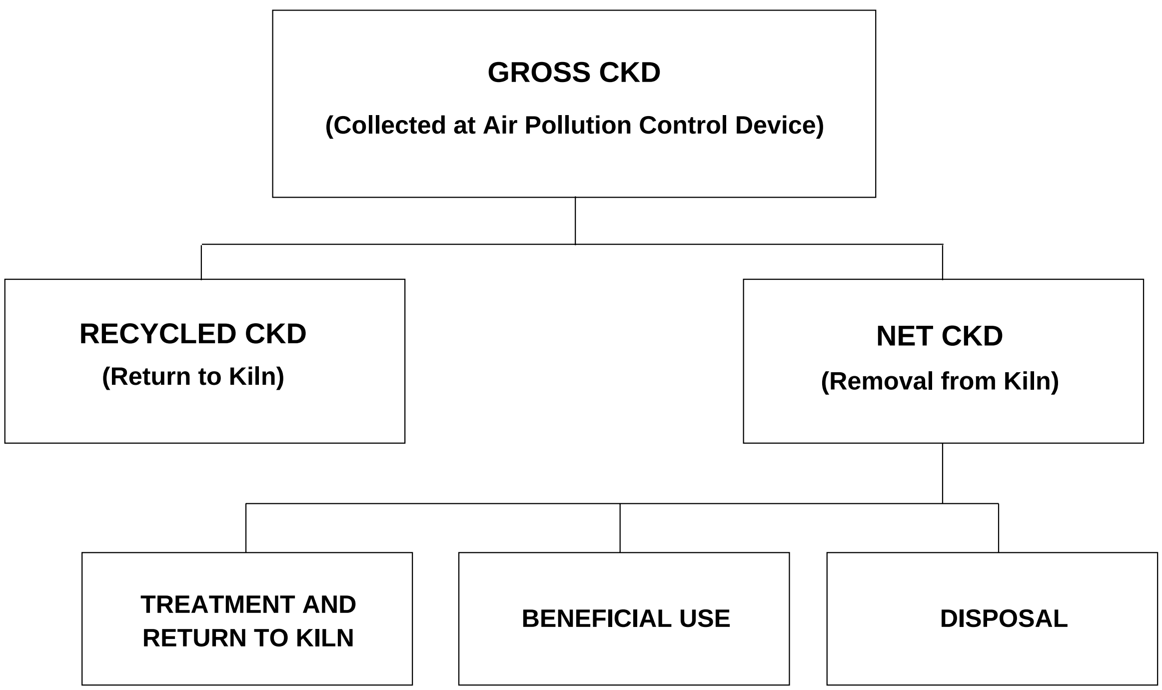
ALTERNATIVE CKD MANAGEMENT PRACTICES AND POTENTIAL UTILIZATION

8.0 OVERVIEW

As discussed in Chapter 3, gross CKD is the dust collected at the air pollution control device(s) associated with a kiln system. Gross CKD is generated as an inherent process residue at all cement plants, though the ultimate fate of this material varies by facility. Exhibit 8-1 illustrates the potential management pathways for gross CKD. After collection, gross CKD is either recycled back to the kiln system or removed from the kiln system as net CKD. Although a number of plants recycle all gross CKD back to the kiln system, most plants remove a significant quantity of CKD from the system. On average, 0.20 tons of gross CKD are generated per ton of clinker produced, and 0.07 tons of net CKD are generated for the same amount of clinker (i.e., about 65 percent of gross CKD is recycled and about 35 percent is removed from the kiln).

Exhibit 8-1

Flow Chart of Gross CKD Management Pathways



When CKD is removed from the kiln system, it can be treated for return to the kiln system, beneficially utilized, or disposed. Net CKD represents a loss of resources when it is removed from the manufacturing process and discarded because CKD is essentially derived from the raw feed (which has been quarried, ground, and blended), and, to a lesser extent, the kiln fuel(s). Additionally, the fuel value of the CKD is lost when the dust at elevated temperatures is removed.[1] Lastly, removing CKD from the system imposes handling, transportation, and disposal costs. Hence, the first efficiency goal of the kiln operator should be to remove less CKD from the kiln system when possible. Second, when CKD must be removed from the kiln system, losses to disposal can potentially be minimized by using this material as a resource.

This chapter discusses the technologies that are available and under development to minimize the quantity of CKD that must be removed from the kiln system and alternative management practices and potential uses for the net CKD that is generated.

8.1 MINIMIZATION OF CKD REMOVAL FROM THE KILN SYSTEM

Conceptually, three general approaches can be used to minimize the removal of CKD from the kiln system:

- Control of CKD generation rates;
- Direct return of CKD to the kiln; and
- Treatment and return of CKD to the kiln.

The first approach involves process controls to minimize dust generation. The other two approaches address methods for returning dust to the kiln system once it is generated and collected. These approaches are discussed below in more detail.

8.1.1 Control of CKD Generation Rates

One approach to minimizing the quantity of net CKD is to generate less gross CKD. Based on the limited information available on this topic, however, there appear to be few practical modifications that can significantly decrease the amount of CKD generated by a given kiln. Nonetheless, there are three primary factors that can influence the gross CKD generation rate within a kiln system. First, dust generation can be minimized by reducing gas turbulence in the kiln and avoiding excessive flow velocities. This practice is, to EPA's knowledge, being implemented to the extent possible as a basic process efficiency parameter. Second, the use of chains near the cool end of the kiln helps to trap CKD before it is entrained into the kiln exhaust.[2] Most kilns are equipped with such cool-end chain sections. Third, the ash content of fuels can vary, yielding differing amounts of particles that become a part of the CKD. For example, liquid hazardous wastes will tend to have a lower ash content than coal.[3] This issue is not likely to drive fuel usage decisions at a kiln.

The amount or percentage by which gross CKD generation can be reduced by any of these factors is not reported in the available literature. Based on the information reviewed, a process-oriented approach to minimizing CKD generation rates appears to have a limited potential impact in comparison to other approaches, such as increased recycling.

8.1.2 Direct Return of CKD to the Kiln

When gross CKD is generated, minimizing its removal from the kiln system involves recycling gross CKD from its collection point(s) to some part of the manufacturing process. According to the 1991 PCA Survey responses, kiln operators recycled 52 percent of the gross

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[1] Based on EPA's sampling study, CKD was removed from the kiln system at a typical temperature exceeding 93 °C (200 °F).

[2] Peray, K.E., 1986. *The Rotary Cement Kiln*. Chemical Publishing Co., Inc. New York, New York. p. 108.

[3] Gossman, D., 1992. *The Reuse of Petroleum and Petroleum Waste in Cement Kilns*. Environmental Progress. Volume 11, Number 1. February. pp. 1-6.

CKD generated in 1990. For each kiln, however, the amount of dust that can be returned to the kiln depends upon (1) the content of minor elements (alkalies[4], sulfur, and chlorine) in the dust; (2) the technology used to recycle the dust; and (3) the type of cement being produced. In addition, the type of kiln system (wet, dry, or preheater/precalciner) will influence the type of return system that can be employed.

Direct return of CKD to the kiln is the simplest recycling practice. Some operators may opt for removal and disposal of CKD rather than installing return systems or monitoring quality. Product specifications and local market demands dictate clinker alkali levels, and thus can influence the quality of CKD that can be returned to the kiln system. Because clinker quality can be reduced by the presence of alkalies and other constituents, in some cement markets, only CKD that is within specified limits for these components can be directly returned to the kiln system in significant amounts. In electrostatic precipitators (ESPs), CKD of acceptable quality is generally only obtained from the initial ESP stages, while the CKD from the later ESP stages is not of sufficient quality for direct return to the kiln because of higher alkali metal content.

As mentioned previously, the major factor limiting the direct recycling of dust to the manufacturing process is its alkali level. The American Society for Testing and Materials (ASTM) specifies a limit of 0.6 percent alkali in portland cement;[5,6] cement with higher alkali content is considered an inferior product and is not suitable for all uses because the alkalies can react with some concrete aggregates and cause the concrete to crack.[7] Similarly, chlorine can react with alkalies to form alkali chlorides, which can also result in structurally-defective concrete. Sulfur, in the form of sulfate, can reduce the structural quality of concrete as well.[8,9] Quality specifications for a given product, which depend upon cement type and local market conditions, will dictate these constituent concentrations in the clinker.

As discussed in Chapter 3, the input materials used to produce cement (raw feed and fuel) influence the chemical composition of the CKD generated. At facilities where a significant quantity of CKD is removed from the system, the use of alternative input materials might improve CKD characteristics so that a larger portion of CKD could be directly returned to the kiln. However, given the weights of these alternative input materials it may be impractical to substitute materials because of high transportation costs.

Fuel inputs can significantly influence CKD chemical characteristics. For example, burning low-sulfur coal instead of less expensive coal that is high in sulfur can yield a reduction in CKD sulfur levels. Similarly, using hazardous waste as fuel can affect CKD alkali levels.[10] Chapter 3 presents data showing that kilns burning hazardous waste recycle less CKD than kilns not burning hazardous waste. This practice is also suggested in the literature. In one

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[4] Alkalis refer to the alkali metals in group IA of the periodic table of the elements, including lithium, sodium, potassium, rubidium, cesium, and francium. These are light, highly reactive metals. Of primary concern to cement producers are sodium and potassium.

[5] Wilson, R.D. and W.E. Anable, 1986. *Removal of Alkalies From Portland CKD*. U.S. Department of Interior, Bureau of Mines Report of Investigations Number 9032. p. 2.

[6] Kosmatka and Panarese, 1990. *Design and Control of Concrete Mixtures*. 13th Ed. Portland Cement Association, Skokie, Illinois. pp. 15-16.

[7] Davis, T.A., *et al.*, 1975. *Disposal and Utilization of Waste Kiln Dust From Cement Industry*. Southern Research Institute. May. p. 17.

[8] Kosmatka and Panarese, 1990, *op. cit.*

[9] Mehta, P.K., 1986. *Concrete: Structure, Properties, and Materials*, Prentice Hall, Englewood Cliffs, NJ.

[10] Gossman, D., 1992, *op. cit.*

study, burning hazardous wastes containing chlorine reportedly resulted in reduced recycling rates. In this study, normal coal-fired operations at a dry kiln yielded 90 metric tons (100 tons) of net CKD per month for disposal. However, when hazardous waste was co-fired, this figure increased to 1,800 metric tons (2,000 tons) per month to limit chloride levels in the system.[11]

Raw feeds also influence CKD quality and recycling rates. The greatest raw feed limitation for the industry appears to be excessive alkali levels in the limestone feedstock. Unlike fuels, which are generally the only major inputs that are transported to a kiln from off-site, limestone feed materials, which account for about 85 percent of the raw material consumption, are almost always quarried on site. Because transportation costs can be prohibitive, the viable options for alternative limestone raw feed inputs are limited for most facilities. Some facilities may, however, find it possible to substitute raw materials, such as sand, shale, or clay. For example, the Calaveras Cement Company facility in Tehachapi, California substitutes the locally-available sand with low-alkali sand (sweet sand), which they purchase from an off-site source. This low-alkali sand balances the high-alkali content of the limestone the facility quarries, thereby enabling the facility to recycle 100 percent of the generated CKD.

Finally, process type appears to affect CKD recycling rates. Chapter 3 demonstrated how, relative to units of clinker product, wet kilns recycle less CKD than dry long kilns, and dry long kilns recycle less CKD than preheater or preheater/precalciner kilns. (The reasons for these differences are not fully understood and analyses are continuing.)

After collection in air pollution control devices and removal of unacceptable CKD, the acceptable portion of the CKD is conveyed back to the kiln system. CKD conveyance mechanisms vary between facilities, but generally consist of augers, belts, positive pressure air conveyors, and negative pressure air conveyors. CKD can be returned to the kiln system at three general locations: CKD can be introduced at the flame (hot) end of the kiln, at the middle of the kiln, or at the raw input (cool) end of the kiln (including blending and storage with the raw mix before reaching the kiln). The equipment needed to return CKD to the kiln system can be expensive, but these costs can be outweighed by the resulting savings on avoided resource losses and CKD management costs.[12] Return system installation costs can also fall within reasonable limits. For example, an Ash Grove Cement Company facility invested $100,000 to install a system to return to the hot end of the kiln the 50 to 90 metric tons of CKD per day that had previously been wasted.[13]

Return to Flame End

Insufflation involves the introduction of unaggregated CKD into the hot end of the kiln. Dust is injected through or near the burner pipe into the kiln, where the CKD very rapidly reaches reaction temperature. In general, the amount of dust returned through insufflation represents about 15 percent of kiln feed. Although this return method is common, two primary limitations exist. First, the amount of dust at a given kiln that can be returned through insufflation is limited by the reduced flame temperature that it causes in the burning zone.[14] A second disadvantage of insufflation is the continuous resuspension of dust that it causes. This

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[11] Engineering Science, 1987. *Background Information Document For The Development of Regulations To Control The Burning of Hazardous Wastes In Boilers and Industrial Furnaces. Vol. II: Industrial Furnaces*. January. pp. 4-18.

[12] Personal communication with Hans Steuch, Director of Engineering, Ash Grove West, December 9, 1992.

[13] *Ibid*.

[14] Steuch, Hans E., 1992. *Review of Dust Return Systems*. Paper presented at the Portland Cement Association Seminar on Emerging Technologies for Kiln Dust Management. March 4. Chicago, Illinois. p. 2.

results in a recirculating dust load that requires additional energy for CKD collection and reheating.[15]

Return to Mid-Kiln

CKD can also be conveyed to a shroud in the middle of the kiln near the material inlet to the calcining zone. Mid-kiln return of the dust is expensive, however, because the kiln must be cut to accommodate the shroud.[16] Scoops mounted on the kiln at this location pick up the dust and drop it into the kiln through openings in the shell. Scoops tend to allow fugitive emissions of dust because of sealing problems between the shroud and the kiln. Use of mid-kiln scoops is not a common dust return method.[17]

Return with Raw Feed

CKD can be returned to the kiln system at the input end (also referred to as the exhaust, or cool end) by combining it with the raw feed. The return process differs between dry and wet kilns. In dry process kilns, the dust is conveyed to kiln feed silos or returned directly to the kiln feed system where it is blended with the raw feed to obtain a uniform mix. In wet process kilns, CKD must be returned in a different manner to avoid hardening and thickening of the feed slurry. There are several solutions to this problem:

- Dry CKD can be added to the feed slurry where the slurry enters the kiln;
- A separate CKD slurry can be formed and pumped directly into the kiln; or
- Chemical additives, such as molasses or lignosulfates, can be added to retard the setting of CKD when it is hydrated, and thereby improving its flow characteristics.[18]

The addition of water and/or chemicals, however, limits the amount of CKD that can be returned,[19] presumably because kiln efficiency would be reduced. In the case of water addition, too much water would require excessive energy for dehydration. In the case of chemicals, the introduction of too many additives could yield recirculating loads of unusable CKD that negate the benefits of treating the material in this manner. Lastly, this alternative can be costly.

8.1.3 Treatment and Return of CKD to the Kiln

CKD that contains alkalies or possesses other undesirable characteristics may be treated so that it can be returned to the kiln system. Although few treatment processes have been commercially adopted on a wide scale, research into CKD treatment and recycling has yielded a number of promising technologies. These include pelletizing, leaching with water, leaching with potassium chloride solution, alkali volatilization, recovery scrubbing, and fluid bed dust recovery.

Pelletizing

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[15] Davis, T.A., *et al*., 1975, *op. cit*.

[16] Davis, T.A., *et al*., 1975, *op. cit*.

[17] Steuch, H.E., 1992, *op. cit*.

[18] Rates of addition are not provided in the reference source.

[19] Steuch, H.E., 1992, *op. cit*.

Pelletizing is generally a physical transformation of CKD that makes it more manageable in certain situations. In addition to pelletizing for return to the kiln system, much CKD is also pelletized prior to disposal in waste management units. This technology has been in existence for over 15 years, and can be used to return CKD to the flame or the feed ends of the kiln.[20] In contrast to insufflation of unaggregated CKD, the pelletizing process gives the CKD the necessary strength to withstand the forces of being fired into the flame without resuspending large quantities of particulate matter. No binder is necessary, and no deterioration is found when the pellets are introduced through the chain section.[21] Pelletizing also avoids the need for any major modification of flame characteristics. The pellets form clinker, which is chemically indistinguishable from normal clinker.[22]

Pelletizing may also involve adding a binder and/or raw feed to the CKD. As discussed below, pelletized CKD can be used with other treatment technologies to improve its handling characteristics. Technologies discussed below in which pelletized CKD has been used include alkali volatilization and fluid bed dust recovery.

Leaching with Water

By leaching alkali salts out of CKD using water, the amount of dust that can be recycled to the kiln can be increased. In the leaching process, dust is mixed with water in a tank or pug mill to produce a slurry of about 10 to 20 percent solids. The slurry is thickened in a clarifier where solids settle to the bottom and excess water overflows the top. The underflow from the clarifier contains about 50 percent solids and is returned to the kiln to produce clinker. In wet process kilns, the underflow slurry is either mixed with the feed slurry or pumped into the kiln through a pipe parallel to the kiln feed.[23] In dry process kilns, the underflow must be filtered and dried before it can be blended with the raw mix or its components. Leaching with hot water has been found to remove more alkali than leaching at ambient conditions.[24,25]

The alkaline wastewater from the leaching process must be treated before it can be discharged because it has a high pH and high concentrations of dissolved and suspended solids. To solve this problem, electrodialysis has been investigated for use after leaching to remove alkali salts from the leachate and to recover salts that may be marketable as fertilizers by evaporation and fractional crystallization.[26] An electrodialysis stack creates an internal electric potential that forces ions from the leachate through semipermeable membranes into a concentrated brine. Water that enters the brine by osmosis carries with it the concentrated salts. The remaining partially desalted water is reused to leach alkali from CKD; no wastewater is discharged.[27] The concentrated brine from the electrodialysis stack contains about 20 percent dissolved solids (mainly potassium, sodium, carbonate, and sulfate). Depending on the ratio of potassium to sodium, the brine may be suitable as a liquid fertilizer, or potassium can be

[20] Sell, Nancy J. and Fritz A. Fischbach. 1978. *Pelletizing Waste CKD for More Efficient Recycling*. Industrial and Engineering Chemistry, Process Design and Development. Volume 17, Number 4. October. pp. 468-473.

[21] *Ibid*.

[22] *Ibid*.

[23] Davis, T.A., *et al*., 1975, *op. cit*.

[24] *Ibid*.

[25] Personal Communication with Henry Voldbaek, Ash Grove, Inkom, Idaho, December 9, 1992.

[26] Davis, T.A., *et al*., 1975, *op. cit*.

[27] *Ibid*.

further purified and concentrated by fractional crystallization and evaporation.[28] In some cases, high calcium concentrations can interfere with electrodialysis. To reduce excessive calcium concentrations, wastewater can be run through two carbonators in which the calcium will combine with carbon dioxide and precipitate out as $CaCO_3$ before the wastewater is sent through the electrodialysis stack.[29] The extent to which these technologies are used commercially, or their associated costs, were not found in the available literature.

Generation of wastewater is not a precondition to the use of alkali leaching, as demonstrated by the Ash Grove Cement, Inkom facility. In a modified version of alkali leaching, the operators of this facility in Idaho concentrate the alkalies in the leaching water to produce a potassium sulfate solution. Ash Grove has been leaching alkalies from CKD and selling potassium sulfate to farmers since the 1950s. In this process, CKD is moved from the air pollution control units to a concrete holding tank using a dust elevator. Water is added to this tank, where the alkalies are leached from the CKD and subsequently concentrated through solar evaporation in two holding ponds; the bottom sludges from the holding tank are pumped to the raw mix slurry tank. The facility operator performs analysis on the sludge returned to the kiln feed to account for input variations. From the evaporation ponds, the facility sells the potassium sulfate for approximately $2.80 per metric ton to a local broker who purchases about 9,000 metric tons (10,000 tons) per year of the product. Local potato farmers spray-apply this solution to their fields. According to Ash Grove Cement, this leaching and return process results in 100 percent recycling of CKD.[30]

In addition to the Ash Grove, Inkom facility, only one other facility is known to treat CKD with water leaching -- the Holnam Plant in Dundee, Michigan. The operators of this facility use a water circulation system to leach alkalies from CKD. In this process, CKD is blown down to a thickening tank for clarification (settling). The slurry contained in the underflow is recycled back to the wet process kiln. The clarified portion of the tank contents is pH-neutralized using waste acid, and directed to a holding tank. From this tank, most of the water is recycled for process water, while a smaller portion is discharged through a NPDES-permitted outfall. This technology produces no saleable byproducts. According to Holnam, the start-up costs for implementing this technology are extremely low.[31]

The economic costs and benefits of CKD leaching with water are described more fully in Chapter 9.

Leaching with a Potassium Chloride Solution

Another procedure to increase the quality, and hence, quantity, of CKD returned to the kiln system involves leaching alkali out of the dust with a potassium chloride solution. In this process, CKD is mixed with a hot KCl solution that produces a slurry high in pH, dissolved solids, and suspended solids. The slurry is then treated with an oily hydrocarbon and a long-chain fatty acid to flocculate the slurry solids for separation.[32] After separation of the solids, the remaining aqueous phase is cooled to induce KCl crystallization. Optimal leaching conditions were found at 70 to 80°C (158 to 176°F).[33] No recent discussion of this technology has been found, suggesting that it has not been applied commercially in the U.S.

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[28] *Ibid*.

[29] Davis, T.A., *et al*., 1975, *op. cit*.

[30] Personal communication with Henry Voldbaek, Ash Grove, Inkom, Idaho, December 9, 1992.

[31] Personal communication with Harry Hackett, Holnam, Dundee, Michigan, January 28, 1993.

[32] McCord, A.T., 1977. *CKD Treatment - By Leaching with Hot Potassium Chloride Solution to Recover Alkali Values*. U.S. Patent No. 4031184.

[33] *Ibid*.

Alkali Volatilization

Alkali volatilization represents another method to recover alkali from the surface of CKD particles. This technique generally involves subjecting the CKD to a high temperature flame, then condensing the resulting alkali vapors from the hot gases onto a cooler surface. (Although volatilization occurs during insufflation under normal kiln operating conditions, separation of the alkali is not accomplished because the alkali recondenses onto the CKD in the kiln rather than being removed.)[34]

Sintering[35] is the primary method used to achieve alkali volatilization from CKD. In one pilot study, pelletized samples were sintered for one to two hours at a temperature of 1,100 to 1,300°C. The study also examined melting pelletized samples at temperatures of 1,600 to 1,700°C for 30 minutes. Researchers noted a first order decomposition of the alkalies in heated CKD through this process, and concluded that the most likely mechanism for the removal of alkalies is the formation of volatile potassium and/or sodium. After thermal treatment, both sintered and melted samples met ASTM standard cement criteria levels for Al_2O_3, CaO, Fe_2O_3, K_2O, and MgO.[36] X-ray diffraction analysis and compression tests also indicated that cement made from sintered or molten CKD would be within ASTM alkali standards. In this study, the alkali content found in sintered or melted CKD was less than 0.094 percent, almost an order of magnitude below the ASTM standard of 0.6 percent. Researchers concluded that temperatures above 1,300°C, and in the presence of carbon (i.e., a reducing atmosphere) are sufficient for effective alkali volatilization from CKD.[37] The current status of this technology has not been determined.

In a similar process, CKD was mixed with fly ash containing alumina, and sintered for the purpose of recovering the alumina.[38] This process involves combining fly ash with CKD and soda ash, pelletizing the mixture, and sintering at temperatures between 1,200 and 1,300°C. The sintered pellets are leached with a dilute solution of soda ash to recover the alumina. The waste from this recovery process is dicalcium silicate, which shows promise as a raw material in the manufacture of low-alumina and conventional portland cement.[39] The current status of this technology has also not been determined.

Recovery Scrubbing

Another CKD treatment technology is the flue gas desulfurization (FGD) process, or recovery scrubber. This process enables all CKD to be recycled as kiln feed by removing alkalies, chlorides, and sulfates from the dust. The recovery scrubber creates a recycling

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[34] Davis, T.A., *et al*., 1975, *op*. *cit*.

[35] Sintering is the process of heating a material such that it becomes a coherent mass without melting.

[36] Wilson, R.D. and W.E. Anable, 1986, *op*. *cit*.

[37] *Ibid*.

[38] Burnet, G., 1987. *Alumina Recovery from Fly Ash by the Lime-Soda Sinter Process*. Proceedings of the International Symposium on Ash. February 2. Pretoria, South Africa.

[39] *Ibid*.

system that produces potassium fertilizer as well as reusable feed, and reportedly discharges only clean air and distilled water.[40,41,42]

Exhibit 8-2 illustrates the various stages of the recovery scrubber process. The first step in the process requires saturating a stream of water with carbon dioxide by introducing it to kiln exhaust gases from the heat exchange process (located at right of the diagram). The CKD input is then mixed with the carbon dioxide-saturated water in the mix tank (on the upper left) to form a slurry. The use

[40] Morrison, G.L., 1990. *CKD and Flue Gas Scrubbing: The Demonstration at Dragon Products Company*.
July. p. 7.

[41] Morrison, G.L., 1991. *Flue Gas Scrubbing and Waste Elimination - An Application of the Recovery Scrubber*. Paper presented at The World Coal Institute Conference and Exhibition on Coal in the Environment. April 3. London, United Kingdom.

[42] Anonymous, 1991. *SO_2 Technology Pays for Itself and Then Some*. Coal and Synfuels Technology. January 14.
p. 1.

Exhibit 8-2

Process Flow Diagram of Recovery Scrubber

of carbon dioxide-saturated water helps to prevent the slurry from setting or solidifying. The slurry is then introduced to the reaction tank of the scrubber. In the reaction tank, the calcium in the slurry reacts with CO_2 from the heat exchange process to form insoluble $CaCO_3$. At the same time, alkali metal (e.g., sodium and potassium) hydroxides react to form the corresponding sulfates.[43]

From the reaction tank, dissolved solids and suspended solids in the reacted slurry are separated into two process streams via a series of settling tanks (bottom left and right) combined with a dilution tank (bottom center) where the slurry is mixed with an equal quantity of water to reduce the alkali content.[44] The dissolved solids are crystallized through evaporation, using waste heat from the kiln exhaust. The suspended solids (minus soluble alkalies, chlorides, and sulfates), are returned to the cement kiln raw material feed system for reuse in the production of cement; the $CaCO_3$ that forms from the calcium and CO_2 yields "new" limestone. The sulfur from the sulfur dioxide and calcium-sulfur compounds in the exhaust gas combines with the potassium in the CKD to make potassium sulfate, which can be used as a fertilizer.[45]

The recovery scrubber reportedly removes 90 to 98 percent of the sulfur dioxide in the flue gas and improves the kiln's particulate CKD capture efficiency.[46,47,48] In addition to increased cement production, the process yields two marketable by-products: potassium sulfate (a fertilizer) and distilled water. According to all available sources, no process waste flows (i.e., waste material in either liquid or solid form) result from the process.[49,50,51] Although water is added to this process, there is no liquid effluent because all the added water is evaporated into the flue gas.[52]

According to Passamaquoddy Technology, which is marketing the system, the process can be widely used with modifications in both wet and dry process cement kilns. Site-specific

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[43] Anonymous, 1991. *Chloride-Free Potash Fertilizer from Waste SO_2 and CKD*. Phosphorous and Potassium. July-August. p. 48.

[44] Morrison, G.L., 1990. *Exhaust Gas Scrubbing and Waste Elimination, An Application of the Recovery Scrubber to a Cement Kiln*. Paper presented at the 1990 SO_2 Control Symposium. May 8. New Orleans, Louisiana.

[45] Anonymous, 1991. *"Home-Grown" Scrubber Protects the Environment of an Indian Reservation*. Sulphur. July-August. p. 24.

[46] Anonymous, 1991. *SO_2 Technology Pays for Itself and Then Some. Coal and Synfuels Technology*. January 14.
p. 1.

[47] Anonymous, 1991. *Recovery Scrubber Meets Design Goals*. Coal and Synfuels Technology. April 22. p. 5.

[48] Morrison, G.L., 1991, *op, cit.*

[49] Morrison, G.L., 1992. *CKD Management Using a Recovery Scrubber: Operation and Economics*. Paper presented at the Portland Cement Association Seminar on Emerging Technologies for Kiln Dust Management. March 4. Chicago, Illinois.

[50] Anonymous, 1991. *Recovery Scrubber Meets Design Goals*. Coal and Synfuels Technology. April 22. p. 5.

[51] Personal communication with Garrett Morrison, Passamaquoddy Technology, November 24, 1992.

[52] Anonymous, 1991. *Chloride-Free Potash Fertilizer from Waste SO_2 and CKD*. Phosphorous and Potassium. July-August. p. 48.

factors requiring design modifications would include kiln characteristics, raw feed characteristics, cement product specifications, and fuel type.[53,54] For example, if these factors yield CKD high in sodium, a double potassium crystallizer would be required to make the potassium sulfate by-product marketable.[55]

Currently, the Dragon Products Company in Thomaston, Maine, owns the only commercial-scale recovery scrubber system in operation. This $18 million[56] trial plant was co-funded by the U.S. Department of Energy's Clean Coal Technology program and began operation in 1990.[57] Although there are no other installations, Passamaquoddy Technology has conducted about 35 plant-specific, engineering evaluations to determine if application of the technology at specific plants is justified and if so, in what configuration.[58] Although it has evoked considerable interest in the United States and abroad, the extent to which this technology will be adopted across the industry is unclear.

With respect to start-up and operating costs, the recovery scrubber system may be more capital-intensive than a traditional system, but the savings in avoided resource losses and CKD disposal costs reportedly yield a net savings. Moreover, the system requires no net increase in personnel. Modifications can, however, significantly increase the cost. For example, a double crystallizer, if required, would add about $1 million to the start-up costs. A continuous metals extractor for the CKD can also be installed for an additional $200,000 to $300,000.[59] The recovery scrubber system also requires higher energy inputs than traditional systems.

The recovery scrubber reportedly confers cost savings due to avoided resource losses and CKD disposal costs. Moreover, the process allows the facility increased flexibility in using high sulfur fuel (which tends to be less costly than low sulfur fuel) in the kiln. Dragon Products expects payback from installation of the recovery scrubber within two to three years. After the payback period, the recovery scrubber at the Dragon facility is expected to generate process savings, avoided CKD disposal costs, and additional income from the sale of by-products.[60,61,62] According to Dragon Products, the potassium sulfate (potash) production rate is expected to range from 7 to 9.1 metric tons per day; this material may be worth as much as $220 per metric

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[53] Morrison, G.L., 1990, *op. cit*.

[54] A discussion of specific design and operating limitations of this process has not been located in any of the available literature.

[55] Personal communication with Garrett Morrison, Passamaquoddy Technology, November 24, 1992.

[56] Personal communication with Garrett Morrison, Passamaquoddy Technology, July 2, 1993.

[57] Anonymous, 1991. *SO_2 Technology Pays for Itself and Then Some*. Coal and Synfuels Technology. January 14.
p. 1.

[58] Personal communications with Garrett Morrison, Passamaquoddy Technology, November 24, 1992 and July 2, 1993.

[59] *Ibid*.

[60] Morrison, G.L., 1992, *op. cit*.

[61] Anonymous, 1991. *SO_2 Technology Pays for Itself and Then Some*. Coal and Synfuels Technology. January 14.
p. 1.

[62] *Ibid*.

ton.[63] According to independent trade and government sources, if the product is of sufficient quality, it may be worth $198 to $355 per metric ton.[64,65]

Dragon Products recycles not only all the CKD it generates, but also consumes CKD from its stockpile of dust generated during previous years. For possibly as many as 100 years, Dragon Products had been disposing its CKD in an on-site pile at a rate, that until recently, averaged 230 metric tons per day. Material from this pile is now being mined and reintroduced to the kiln at a rate of approximately 90 to 270 metric tons per day, so that Dragon Products expects to eliminate its existing CKD waste pile in the near future.[66,67]

In addition to recycling their own dust, it may be possible that cement plants with recovery scrubbers could consume wastes generated by other industries, such as paper mills and biomass-burning power plants, and charge a tipping fee for the service. Dragon Products will reportedly be accepting about 45,000 metric tons per year of wood and coal ashes, at a tipping fee of $33 per metric ton.[68] Other wastes that reportedly can be accommodated include acids or bases and ash from other burners.[69,70]

The economic costs and benefits of the recovery scrubber technology are examined in further detail in Chapter 9.

Fluid Bed Dust Recovery

The fluid bed dust recovery process, or Fuller process, thermally treats the CKD (on either a gross or net basis). Although this process does not return CKD to the kiln system, it is functionally similar to such return technologies because it yields a usable cement clinker product rather than treated CKD. The fluid bed process is designed to accept all CKD generated from a kiln, pelletize it, and calcine it into clinker on a fluid bed instead of in a typical rotary kiln.[71] The unusable constituents are concentrated into a waste dust that represents 10 percent of the original input dust volume.

During pelletization, CKD enters a pug mill, where the free lime in the CKD reacts with introduced moisture, and the CKD is pelletized. Generally CKD requires only water for pelletization. However, in some cases, a binder (e.g., five percent portland cement) may be required. As illustrated in Exhibit 8-3, the Fuller process operates on a gravity system, in which dried CKD pellets are gravity fed into the reaction zone of the fluid bed reactor for a retention

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[63] Personal communication with Garrett Morrison, Passamaquoddy Technology, July 2, 1993.

[64] Chemical Prices Weekly, 1992. *Potassium Sulfate*. Ending December 25. p. 28.

[65] Bureau of Mines, 1989. *Minerals Yearbook, Vol. 1, Metals and Minerals, Potash* (James P. Searls auth.). Department of the Interior. pp. 801-805.

[66] Anonymous, 1991. *"Home-Grown" Scrubber Protects the Environment of an Indian Reservation*. Sulphur. July-August. p. 24.

[67] Morrison, G.L., 1990, *op. cit.*

[68] Personal communication with Garrett Morrison, Passamaquoddy Technology, July 2, 1993.

[69] Anonymous, 1991. *"Home-Grown" Scrubber Protects the Environment of an Indian Reservation*. Sulphur. July-August. p. 24.

[70] Morrison, G.L., 1990, *op. cit.*

[71] Cohen, S.M., 1992. *Fluid Bed Dust Recovery*. Paper presented at the Portland Cement Association Seminar on Emerging Technologies for Kiln Dust Management. March 4. Chicago, Illinois.

time of 1-2 hours. The pelletized CKD reacts to form clinker and moves along the fluid bed and drops into a pipeline for cooling and subsequent grinding.[72]

In the fluid bed, the combustion and calcining gases flow upward and are directed away from the raw feed. The gases released from the clinkering process exit the fluid bed without contacting the incoming raw material. In contrast, the exhaust gases in conventional cement kilns contact incoming raw material and reprecipitate alkalies onto the raw material particles. The fluid bed process reportedly removes as much as 90 percent of the K_2O, 70 percent of the Na_2O, 90 percent of the SO_3, and almost 100 percent of the chlorides contained in the original feed dust. These compounds are concentrated in the unusable dust fraction (i.e., 10 percent of the original CKD input) that is removed from the fluid bed system by directing exhaust through a baghouse.

The fluid bed process yields clinker output at 60 percent of the CKD input (i.e., 0.6 tons of clinker is generated per ton of CKD input). Waste dust is generated at approximately 10 percent of the CKD input. The fate of the remaining 30 percent of the original CKD input has not been addressed. Presumably, it is either returned to the system or lost as gaseous emissions or both. These generation rates are comparable to those of kilns using virgin raw materials. Because the unusable dust contains approximately 40 percent potassium, it may be of value as a fertilizer feedstock. Further evaluation is needed, however, to assess the effects of other constituents that may also be present in the dust. The presence of heavy metals presents one potential concern, although initial tests indicate that the unusable dust from the Fuller process is no higher in heavy metals than dust from conventional rotary kiln cement processes.[73]

A wide range of solid fuel sources (e.g., coal, petroleum coke) can be added to CKD during pelletization to provide up to 90 percent of the process energy requirement. A clinker bed moves above a grid plate through which air is driven. This clinker bed is held at 1,300°C by injection of oil or gas directly into the moving bed of material. The added fuel supplies the remaining 10 to 15 percent of the heat requirement after the fuel in the pellets is burned. Projected fuel consumption for a commercial level plant is 1.15 million kilocalories (Kcals) per metric ton (4.14 million Btus per ton) of clinker. According to Fuller, this figure is competitive with both wet and long dry commercial systems but not with preheater or flash calcining systems, if compared to normal clinker production. This claim is verified by the data in Exhibit 2-7 of this report. As shown in Exhibit 2-7, energy consumption (Kcal/Kg of output) is 1,529 to 1,668 for wet process kilns, 1,251 to 1,390 for dry process kilns, 945.2 for semi-dry kilns, and 750.6 to 889.6 for preheater kilns. Specific information is not available for precalciner kilns, but the energy consumption of such kilns is believed to be similar to that of preheater kilns. The Fuller process minimizes energy loss by reclaiming the heat contained in exhaust gases with a heat recovery system.[74,75]

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[72] *Ibid*.

[73] Personal communication with Sidney Cohen, Fuller Company, July 20, 1993.

[74] *Ibid*.

[75] Personal communication with Sidney Cohen, Fuller Company, November 13, 1992.

Exhibit 8-3

Process Flow Diagram of Fluid Bed Dust Recovery Process

This technology has only been used to date on a pilot scale. Although reportedly ready for market, this system is still undergoing extensive research. For example, a uniform set of operational parameters has not yet been developed. Tests indicate that the operational parameters are facility-specific, and that system designs would have to be individually tailored. Many aspects of the reaction dynamics are also not fully understood. The end product and by-products of the reactor are being analyzed to confirm cement (clinker) quality and to determine the dynamics of the recovery process as they relate specifically to metallic and other components. Material and heat balances are being developed to establish the overall energy consumption for the process, as well as to provide data for economic evaluations.[76]

In pilot scale tests, this system has successfully produced a clinker product and a highly concentrated alkali dust product using CKD from 10 different cement plants. The fluid bed recovery process can provide the benefit of generating a usable product, and decrease by up to 90 percent the amount of CKD that is regularly disposed. The remaining 10 percent of the received CKD becomes a potentially marketable by-product that is high in potassium. Alternatively, this material can be leached to remove alkalies, producing solids that can be returned to the process and a highly concentrated solution that can be utilized for chemical production.[77] As mentioned above, the economic viability of the process depends on each facility, and is a function of the quantity of dust generated, kiln capacity, and dust management costs. Therefore, a unit cost for the process is not realistic.[78] According to the manufacturer, estimated capital investment for a complete 270 metric ton per day (300 TPD)[79] installed system (as CKD input, to produce up to 160 metric tons clinker) would be $9 to $10 million,[80] with an estimated payback period of six years.[81]

8.2 BENEFICIAL USE OF REMOVED CKD

It is likely that even with advances in recycling technologies, some CKD will need to be removed from kiln systems. Because resources are lost when CKD is permanently disposed, and because disposal practices can be burdensome, finding alternative uses for waste CKD can help facilities avoid disposal costs and even generate additional revenue. CKD has been used beneficially for at least 15 years, and interest in uses for CKD as a valuable resource appears to be growing. According to responses from the 1991 PCA Survey and §3007 requests, 779,916 metric tons (859,709 tons) of CKD were used beneficially in 1990, or 5.4 percent of the gross CKD generated in 1990, and about 16 percent of the net CKD for that year. Of this total, about 71 percent (670,000 metric tons) was used for waste stabilization, 12 percent (111,000 metric tons) for soil amendment, 5.6 percent (53,000 metric tons) as liming agent, nearly three percent (25,000 metric tons) as materials additive, about one percent (11,000 metric tons) as road base, and eight percent (76,000 metric tons) for other uses.

The ASTM suggests that CKD may be useful in a variety of applications, including construction, stabilization, waste treatment, and agriculture. Due to the variability in dust composition, however, ASTM advises that use of CKD should be undertaken only after the material's characteristics have been properly evaluated with respect to the intended application.

[76] Cohen, S.M., 1992, *op. cit*.

[77] Personal communication with Sidney Cohen, Fuller Company, July 20, 1993.

[78] Personal communication with Sidney Cohen, Fuller Company, November 13, 1992.

[79] An installation of this size would be adequate to treat total net dust generated at most plants in the U.S.

[80] Cohen, S.M., 1992, *op. cit*.

[81] Personal communication with Sidney Cohen, Fuller Company, November 13, 1992.

ASTM also recommends frequent performance testing until the degree of variability has been established.[82]

Currently, CKD is used beneficially for sludge, waste, and soil stabilization, land reclamation, waste remediation, acid neutralization, agricultural applications, such as fertilizer and lime substitution, and construction applications. These CKD uses, however, appear to represent only a portion of potential beneficial applications for this material. The manner and extent of CKD adaptation for beneficial applications is in constant flux as research and development of CKD use continue to grow.

8.2.1 Stabilization of Sludges, Wastes, and Contaminated Soils

CKD has been used as an agent to solidify and stabilize waste materials and contaminated soils since at least 1982. According to respondents to the 1991 PCA Survey and §3007 requests, 70.8 percent of the CKD that was sold or given away was used for waste stabilization. CKD has been used with reported success on sewage sludge, waste oil sludge, and miscellaneous other wastes. The elevated pH of CKD helps to neutralize the acid conditions and decrease the mobility of heavy metals in these materials. CKD can also help to dewater contaminated materials and thereby increase weight-bearing capacity and possibly reduce the threat of leachate migration.

Sewage Sludge

Economical and effective treatment technologies for municipal sewage sludge have been sought for many years. Without treatment, sludge may contain unwanted microbial pathogens and it may not be in a solid form conducive to handling. Treating the sludge with CKD may improve its physical, chemical, and biological characteristics. For example, trace metals in the sludge are immobilized by precipitation and coprecipitation as carbonates, oxides, hydroxides, phosphates, and sulfates.[83] A considerable amount of research has been conducted on the use of CKD as a medium for dewatering and stabilizing raw or digested sewage treatment sludges.[84,85,86,87,88]

Presently, CKD is being used commercially to stabilize municipal sewage sludge by at least two companies: (1) Keystone Cement Co., which markets CKD under the name StableSorb as a sewage sludge dewatering agent; and (2) National N-Viro Energy Systems (N-Viro), which markets a CKD-stabilized sewage sludge as N-Viro Soil.

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[82] ASTM, 1991. *Standard Guide for Commercial Use of Lime Kiln Dusts and Portland CKDs*. 1990 Annual Book of American Society for Testing and Materials Standards. Volume 11.04. Method Number D5050-90. pp. 172-174.

[83] Based on notes developed by ICF Incorporated during the 5th Annual International Conference on Alkaline Pasteurization and Stabilization, Somerset, New Jersey, May 18-19, 1992.

[84] Anonymous, 1985. *Mobile Hazardous Waste Treatment Services - What's Available?* Hazardous Waste Consultant. September-October.

[85] Burnham, J.C., *et al.*, 1990. *CKD Stabilization of Municipal Wastewater Sludge*. Annual International Solid Waste Exposition "Vancouver 90." August. Canada.

[86] Kovacik, T.L., 1988. *Sludge, Kiln Dust Make Fertilizer*. Water Engineering Management. December.

[87] Metry, A.A., *et al.*, 1985. *A Cost-Effective Approach For Stabilization and Closure of an Organic Waste Superfund Site*. 31 Annual Meeting of the Institute of Environmental Sciences. April 29. Las Vegas, Nevada.

[88] Zier, R.E. and E. Wood, 1991. *Sludge: Sludge Solutions*. Waste Information Digests. May.

The treated sludges have been used as landfill cover, structural fill material, dike construction material, and for agricultural purposes.[89,90,91] Agricultural application of sewage sludge has also been a common method of sludge management. Sludge contains a number of nutrients beneficial to plants, including nitrogen, phosphorus, sulfur, calcium, potassium, magnesium, and a host of nutrients needed in small quantities.[92] Because, however, these nutrients can occur within a wide range of concentrations, sludge used for agricultural purposes may require nutrient supplements.

In 1992, Keystone sold over 38,000 metric tons (42,000 tons) of StableSorb, a considerably lower figure than its record sales of 74,000 metric tons in 1990, but greater than its 1991 total of 25,000 metric tons. The anomalously high figure for 1990 was apparently the result of an unusually large project that used StableSorb during that year.[93] The low price of CKD compared to its substitutes makes it highly competitive in the market. Keystone sells the dust for $10 per metric ton ($9 per ton) F.O.B. (freight on board)[94]. Transportation costs, however, can add up to $22 per metric ton ($20 per ton) to the sale price of the dust. Keystone supplied CKD for two years to a utility in New Jersey for use in waste stabilization. Prior to the use of CKD, the utility used fly ash for this purpose. The utility combined the dust and waste in a slurry tank, in which the waste was thereby stabilized; the stabilized waste was used as a landfill cover. They also blended CKD with dry wastes to form a landfill filler. Some buyers have been concerned about potential dust quality impacts when Keystone burns hazardous waste as a kiln fuel. According to Keystone, these concerns have been allayed through the use of constituent test results, though Keystone is reportedly not selling StableSorb pending EPA's regulatory determination for CKD. For specialized requests, Keystone will modify the CKD by blending it with cement to give the product more strength. For such a treatment, the price increases by the percentage of added cement multiplied by $55 per metric ton (e.g., a 10 percent blending adds $5.50 per metric ton to the price).[95]

N-Viro Soil is used with or instead of lime to disinfect and deodorize municipal sewage sludge, and according to the company, it provides a safe and socially-acceptable solution for treating the sludge. N-Viro Soil is produced by combining CKD and municipal sludge through a patented process called "Advanced Alkaline Stabilization with Subsequent Accelerated Drying." This N-Viro technology uses a combination of microbiological stresses to kill pathogens and stabilize the sludge to produce what is described as "a soil-like product." CKD's high alkali and

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[89] Keystone Cement Company, date unknown. *Stablesorb: A Coproduct of Cement Manufacturing With a Variety of Uses*. Product Brochure.

[90] Burnham, J.C., 1988. *CKD/Lime Treatment or Municipal Sludge Cake, Alternative Methods For Microbial and Odor Control*. Paper from Proceedings of National Conference on Municipal Sewage Treatment Plant Sludge Management. June 27-29. Palm Beach, Florida.

[91] Personal communication with J. Patrick Nicholson, N-Viro Soil, December 7, 1992.

[92] Kelley, W.D., D.C. Martens, R.B. Reneau, Jr., and T.W. Simpson, 1984. *Agricultural Use of Sewage Sludge: A Literature Review*. Bulletin 143. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. December. p. 38.

[93] Personal communication with Doug Glasford and Bill Fischer, Keystone Cement, November 24, 1992.

[94] The F.O.B. price of a product is the price that would be charged if the product were to be picked up from the shipping dock; it excludes the cost of loading goods aboard a carrier, transportation costs, and all other costs beyond the port of export.

[95] *Ibid*.

exothermic properties produce a pH of about 12 and generate temperatures between 52 and 62°C when mixed with the moisture contained in sewage sludge.[96]

N-Viro Soil contains between 35 and 75 percent CKD by weight. The alkali and CaO content of CKD reportedly contribute to the characteristics of the product and make it a suitable agricultural lime substitute. The large surface area and low moisture content of fine-grained CKD particles provide odor control and accelerate drying. When combined with sludge, CKD reportedly dilutes trace metal concentrations and reduces the solubility of trace metals. Further, the heat produced from the hydrolysis reaction between CKD and the sludge moisture, combined with elevated pH levels, apparently kills all pathogens in the sludge.[97] In addition, this mixture produces an artificial soil that can be used as a cover material for landfills and as an agricultural lime substitute for soils.[98] CKD also contributes most of the base elements (i.e., Ca, Mg, K, Na) in N-Viro Soil that make the product a useful soil amendment.[99] The product reportedly can be stored for long periods of time without deterioration.[100,101] One of the primary drawbacks of N-Viro Soil is that a relatively large quantity of kiln dust is required to treat a given unit of sludge, meaning that significant quantities of CKD must be transported and handled to treat a given quantity of sludge.[102]

Regulations that govern the quantity of metals that can be applied to land in sludge may limit the application rate of CKD-stabilized sludge (since sludge itself has high metals concentrations);[103] N-Viro Soil ostensibly meets these requirements.[104,105] In addition, 40 CFR Part 503, promul-gated on November 27, 1992, has established permitting regulations with respect to sludge use and disposal practices.[106] According to N-Viro, their purchases of CKD must meet specifications for metals levels set by EPA's clean sludge rule as outlined below:

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[96] N-Viro Energy Systems, 1991. Promotional Bulletin - N-Viro Soil.

[97] Personal communication with Robert Bastian, Office of Wastewater Enforcement and Compliance, EPA, November 1992.

[98] *Ibid*.

[99] N-Viro Energy Systems, 1991, *op. cit*.

[100] In tests, N-Viro Soil has apparently been stored for over 500 days. (PR Newswire, September 21, 1988).

[101] Kovacik, T.L., 1987. *Successful Recycling for Sludge and Solid Waste*. BioCycle Southeast Conference. November 4. Orlando, Florida.

[102] Personal communication with Robert Bastian, Office of Wastewater Enforcement and Compliance, EPA, November 1992.

[103] *Ibid*.

[104] Anonymous, 1988. *Toledo City Council Approves Five-Year Contract With National N-Viro Technology, Inc. For Sewage-Agricultural Facility*. PR Newswire. September 21.

[105] Burnham, J.C., 1988, *op. cit*.

[106] Personal communication with Robert Bastian, Office of Wastewater Enforcement and Compliance, EPA, November 1992.

Constituent	Concentration Limit (ppm)
Arsenic	<41
Cadmium	<39
Chromium	<1200
Copper	<1500
Lead	<300
Molybdenum	<18
Mercury	<17
Nickel	<490
Selenium	<36
Zinc	<2800

The greatest barrier to CKD use is likely to be the lack of specifications for metals contents and products of incomplete combustion (PICs). N-Viro reportedly does not purchase CKD from plants that burn hazardous waste. However, this policy is followed more because of public perception than for technical reasons.[107]

The N-Viro process appears to be less costly than existing methods of sludge treatment. In 1988, the city of Toledo, Ohio, signed a five-year contract with National N-Viro Energy Systems to build and operate a $3 million facility to convert sewage sludge into fertilizer. Toledo's Director of Public Utilities stated that a comparable composting plant would have cost $25 to $30 million.[108] The cost of operating the plant was estimated at about $39 per wet metric ton ($35 per wet ton), after dewatering, compared to the $52 per wet metric ton that the city was spending at the time to haul its sludge to a reclamation project. The city expects to realize a profit from fertilizer sales resulting from the project within five years.[109]

The use of N-Viro Soil has increased rapidly as indicated by sales of the product that have doubled each year for the past four years. In 1992, more than 900,000 metric tons of N-Viro Soil were sold.[110,111] Some CKD obtained by N-Viro goes to uses other than sewage sludge stabilization. Although 80 percent of the CKD the company sells is used to stabilize sewage by producing N-Viro Soil, the remaining 20 percent is sold as dust for direct application in other beneficial uses.[112] The company claims that use of N-Viro Soil has resulted in substantial savings (more than $42 per acre) to farmers by reducing chemical fertilizer costs and by increasing yields on crops such as soybeans, corn, and alfalfa.[113] N-Viro Soil mixed with fly ash has also been used as an aggregate diking material in Wilmington, Delaware.[114] The product is, however, expensive to transport. N-Viro sells 136,000 metric tons a year to a company in New Jersey at $28 to $39 per metric ton, of which transportation costs represent 50 percent.[115]

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[107] Personal communication with J. Patrick Nicholson, N-Viro Soil, December 7, 1992.

[108] Anonymous, 1988. *Toledo City Council Approves Five-Year Contract With National N-Viro Technology, Inc. For Sewage-Agricultural Facility*. PR Newswire. September 21.

[109] Anonymous, 1988. *Toledo Tries a Sludge First*. Engineering News-Record. September 29.

[110] CKD comprises only about 35 percent of this N-Viro soil.

[111] Personal communication with J. Patrick Nicholson, N-Viro Soil, December 7, 1992.

[112] *Ibid*.

[113] Anonymous, 1992. N-Viro Achieves Record Year. PR Newswire. February 19.

[114] Personal communication with Robert Bastion, Office of Wastewater Enforcement and Compliance, EPA, November 1992.

[115] Personal communication with J. Patrick Nicholson, N-Viro Soil, December 7, 1992.

Although N-Viro's technology has grown rapidly as a promising management alternative for CKD that would otherwise be disposed, several factors may impede its market growth potential. Such factors include regulatory uncertainties.[116] Alternative additives may also reduce the importance of CKD to sewage sludge stabilization. For example, N-Viro also uses sulfur scrubbing residue and fluidized bed residue as a sludge additive, because these materials have more activated carbon and impart better odor control than CKD.[117] Although any trend is unclear, these substances may replace CKD in the future.

Sewage sludge stabilization has been implemented on a more modest commercial scale as well. In Cayce, South Carolina, government regulations required treatment of activated sewage sludge before landfill disposal. After evaluating several processes, the city opted for a screw press dewatering system, supplemented by the application of CKD. The sludge is dewatered to a cake before it is mixed with the dust. The dust raises the cake's pH level from 9.0 to 11.2 to destroy bacteria and other pathogens and chemically binds any heavy metals in the sludge. The new system has reportedly saved the city money and keeps odors to a minimum.[118]

Oil Sludge

In addition to municipal sludge stabilization, the use of CKD to solidify oil sludge has also elicited a fair amount of interest and research.[119,120,121] According to one source, CKD has proven to be one of the most efficacious and economical means of solidifying non-recoverable waste oil sludge, producing a stable and compactible fill material with good compressive strength. Solidification of oily sludge in landfills makes it possible to use a reclaimed landfill site for industrial construction.[122]

In 1983, CKD was used by the city of Wichita, Kansas, to solidify highly acidic oil sludge. Oily sludge had accumulated during the 1950s and 1960s in the John's Sludge Pond from the oil recycling and reclamation operations of Super Refined Oil Co. The use of sulfuric acid to refine waste oil for recycling created an acidic layer on top of the sludge pond that frequently overflowed into nearby surface waters. In 1983, under orders from EPA, the city excavated and solidified the sludge using CKD with redeposition of the treated sludge into a compacted clay-lined cell followed by capping, using a compacted clay cap. No contaminant levels requiring further action were detected in surface and ground water following this action.[123]

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[116] *Ibid*.

[117] *Ibid*.

[118] Billings, C.H., 1992. *Screw Press/Kiln Dust Combination Doubles Drying Bed Production*. Public Works. May.

[119] Morgan, D.S., *et al.*, 1984. *Oil Sludge Solidification Using CKD*. Journal of Environmental Engineering. October.

[120] Thorsen, J.W., *et al.*, 1983. *In Situ Stabilization and Closure of an Oily Sludge Lagoon*. 3rd Ohio Environmental Conference. March. Columbus, Ohio.

[121] Zarlinski, S.J. and J.C. Evans, 1990. *Durability Testing of a Stabilized Petroleum Sludge*. Paper from Hazardous and Industrial Wastes, Proceedings of 22nd Mid-Atlantic Industrial Waste Conference. July 24-27. Pennsylvania.

[122] Morgan, D.S., *et al.*, 1984, *op. cit*.

[123] Environmental Protection Agency, Office of Emergency and Remedial Response, 1989. *Superfund Record of Decision (EPA Region 7): John's Sludge Pond, Wichita, KS, (First Remedial Action)*. Washington, DC., September 22.

In another example, CKD was used to solidify oil sludge during a site remediation project near Dallas, Texas, in 1982. Operators determined CKD to be the best of several alternatives in terms of chemical properties and cost effectiveness. The reaction of CKD with water to form calcium hydroxide removed a significant portion of the free water from the sludge. This reaction also provided a solid matrix of sufficient density and weight-bearing capacity that it could be used as a fill. In addition, the binding effect of the kiln dust reportedly prevented the oil from leaching out of compacted layers in the landfill to which it was transferred.[124] The project required an estimated 68,000 metric tons of kiln dust, which was blown into the sludge pit. During the project, operators found that stockpiled kiln dust required a greater dust-to-oil mixing ratio than recently generated dust,[125] presumably because the newer dust contained more unreacted lime.

Acid Waste

The alkaline nature of CKD makes it an effective neutralizing agent for treating acidic materials. Substances that have been neutralized with CKD include industrial acidic wastes, such as spent pickle liquor, and wastes from leather tanning and cotton seed delinting processes.[126] Liquid hazardous wastes have been neutralized, oxidized, or reduced, and then solidified by the addition of CKD and fly ash to form material that has the consistency of coarse gravel.[127]

As discussed below in more detail, CKD can also be used in land reclamation activities to neutralize acid mine drainage,[128] and has reportedly been used to neutralize acidic wastewater.[129] Other neutralization possibilities include CKD use to treat acidic mine waste piles and leachate from hazardous waste and sanitary landfills.

Miscellaneous Wastes and Contaminated Soils

The use of CKD as a solidifying and stabilizing medium for a variety of wastes and contaminated soils, in addition to municipal sludge, oil sludge, and acid wastes, has been studied on several occasions. For example, laboratory studies have been conducted on the use of CKD in conjunction with portland cement and rice husk ash to immobilize synthetic wastes containing cadmium, lead, aldrin, chlordane, and electroplating wastes.[130] Researchers have also investigated the use of CKD to solidify and stabilize contaminated dredged materials.[131] Some uses have been implemented in the field as well. Some examples of miscellaneous CKD stabilization uses are summarized below:

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[124] Anonymous, 1982. *A Method For Oil Sludge Solidification and Disposal Using CKD Has Reclaimed 133 Acres Near Dallas, Texas*. Waste Age. April.

[125] N-Viro Energy Systems, 1991, *op. cit*. pp. 100-102.

[126] Davis, T.A., *et al.*, 1975, *op. cit*.

[127] Razzell, W.E., 1990. *Chemical Fixation, Solidification of Hazardous Waste*. Waste Management Resources. April.

[128] Davis, T.A., *et al*., 1975, *op. cit*.

[129] Personal communication with Ben Haynes, Engineering, Technology, and Research Division, Bureau of Mines, U.S. Department of the Interior, November 1992.

[130] Ahn, K.H., *et al.*, 1988. *Solidification of Hazardous Wastes: An Approach Using Cementitious Binders*. Paper From Proceedings of 1988 Pacific Basin Conference on Hazardous Waste. February 1-6. Honolulu, Hawaii.

[131] Betteker, J.M., *et al.*, 1986. *Solidification/Stabilization of Contaminated Dredged Material*. Proceedings of Mid-Atlantic Industrial Waste Conference. June 29-July 1. Lancaster, Pennsylvania.

- In 1988, EPA initiated an ash solidification project to evaluate the performance of several techniques, including mixing incinerator ash with CKD. CKD was used to stabilize the ash and harden the mixture into a monolithic block, improving the physical and handling characteristics of the ash.[132]

- In Brisbane, Australia, non-degradable liquid hazardous wastes are chemically treated and then solidified by the addition of fly ash and CKD before permanent burial in clay cells. The wastes include pesticides, paints, organic solvents, and oily wastes. The researchers concluded that leaching test results have been "below 10 times EPA drinking water guidelines."[133]

- The use of CKD to treat sludges can make it possible to use on-site management techniques instead of more expensive off-site disposal alternatives. CKD was used to stabilize an organic sludge at a Superfund site. The stabilized material reportedly provided a sound base for the final cover system.[134]

- Experiments have demonstrated the potential use of CKD to stabilize PCB-contaminated sites. Last year, however, EPA's Risk Reduction Engineering Laboratory found that the heat produced from the quicklime reaction with PCBs causes these carcinogens to volatilize. The Agency stated that further experiments were planned to examine PCB decomposition and volatilization under simulated field conditions.[135]

8.2.2 Soil Stabilization

As a soil stabilizer, CKD can decrease shifting, subsidence, fugitive dust emissions, and erosion, and thereby provide temporary or permanent stability of soil at locations such as construction sites. It mixes easily with existing soils and maximizes compacted density. Respondents to the 1991 PCA Survey indicated that 12 percent of the CKD used beneficially was used as a soil amendment, some of which probably included soil stabilization. According to Keystone Cement, use of CKD as a soil stabilizer reduces construction costs when it is used to speed up construction schedules (e.g., due to reduced necessary paving thickness, reduced dewatering time).[136]

Blending CKD with other soil stabilizing agents can also be effective. For example, CKD has been found to enhance the ability of waste sulfate to stabilize and strengthen soils. The addition of fly ash to such a mixture can further improve soil strength.[137] CKD can be injected like lime into the ground using rig-mounted tubes that can be driven to desired depths, or it can be mixed with soil using earth moving equipment. Keystone Cement and N-Viro both market CKD as a soil stabilization product.

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[132] Anonymous, 1988. *EPA, Cities, Industry Press Congress For Incinerator Ash Legislation*. Cogeneration Report. April 22.

[133] Razzell, W.E., 1990, *op. cit*.

[134] Metry, A.A., *et al.*, 1985, *op. cit*.

[135] Anonymous, 1991. *Quicklime Volatilizes PCBs, EPA Finds*. Superfund. June 28.

[136] Keystone Cement Company, *op. cit*.

[137] Nebgen, J.W., *et al.*, 1976. *Use of Waste Sulfate For Remedial Treatment of Soils, Volume I, Discussion of Results*. U.S. Department of Transportation, Federal Highway Administration. August.

8.2.3 Land Reclamation[138]

In a manner similar to that used for soil stabilization, CKD has been utilized to reclaim settling ponds, lagoons, or other lands. The added CKD stabilizes and dewaters these lands and can render them useful for industrial, commercial, or residential purposes. Unlike other reclamation procedures, processes, and materials, CKD can reportedly accommodate many treatment procedures without the use of additional materials.[139] The use of CKD to reclaim lands that have been mined has also been studied.[140] CKD is marketed by Keystone Cement and N-Viro for use in land reclamation projects.

In addition to the high lime content in CKD, the easy flowing nature of CKD makes it an attractive neutralizing agent to pump into abandoned mines to treat acid mine drainage. In 1975, one cement plant reportedly disposed CKD in strip mines where it neutralized acid mine drainage and precipitated iron from the run-off water.[141] This treatment method may also help reduce seepage of water from the mine.[142] Specific quantities of CKD and water treated were not provided in the literature, and EPA has not found more recent accounts of CKD use in mine reclamation.

8.2.4 Agricultural Applications

CKD, like agricultural lime, is alkaline and contains a number of essential plant nutrients. Because of these parallel characteristics, CKD has been used as an agricultural soil amendment for a number of years. For example, in the mid-seventies, many U.S. cement manufacturers reported that local farmers would occasionally visit their plants and haul away truckloads of kiln dust to spread on their fields.[143] To better understand the advantages and limitations of CKD as an agricultural amendment, numerous studies (cited below) have been conducted. These studies, many of which took place outside of the United States, have sought to determine such factors as the fertilizer equivalence and the lime equivalence of CKD, so that optimal CKD application rates could be determined. The use of CKD as fertilizer and as a liming agent is discussed below.

Fertilizer

Respondents to the 1991 PCA Survey and §3007 requests indicated that 11.7 percent of the CKD used beneficially was as a soil amendment, some or all of which probably included use as a fertilizer. CKD possesses significant fertilizer potential, particularly because of its high potassium content. It has been used to this end at state and local levels in Ohio, Illinois, and Pennsylvania because it provides savings over substitute products.[144] Researchers have suggested that a 0.9 metric-ton-per-acre (one-ton-per-acre) application of CKD would meet the

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[138] Land reclamation efforts generally attempt to restore lands adversely affected by human activity to their original state.

[139] Keystone Cement Company, *op. cit*.

[140] Libicki, J., 1984. *Reclamation in Mountains, Foothills, and Plains: Doing it Right*. 9th Annual Meeting of the Canadian Land Reclamation Association. August 21. Canada.

[141] Davis, T.A., *et al.*, 1975, *op. cit*.

[142] *Ibid*.

[143] *Ibid*.

[144] Personal communication with Marc Saffley, Soil Conservation Service (SCS), November 18, 1992.

initial potassium requirement for corn on many soils.[145] Soil scientists have also suggested that other key plant nutrients contained in CKD, such as calcium, phosphorus, and zinc, might be beneficial in some fertilizer applications.[146,147]

Numerous agricultural studies have been conducted to address specific applications of CKD as a fertilizer. In Russia and Poland, several studies found CKD to be an acceptable and inexpensive fertilizer for potatoes. Unlike most inexpensive potassium fertilizers, which contain high amounts of undesirable chloride, the CKD used in this study had essentially no chloride. Also, the sulfate in the dust led to a higher starch content in potatoes.[148] Dutch researchers found that comparable yields of oats were achieved when CKD versus limestone and K_2SO_4 were used as fertilizer. Mixed peas-and-oats crops fertilized with kiln dust contained slightly more protein than crops grown with KCl fertilizer. In comparison to KCl-fertilized crops, the dust was also found to yield fodder containing more starch, and sugar beets containing more sugar.[149] In a Czechoslovakian study, pot experiments using cereals and sunflower as test crops showed that CKD was similar in effect to a potassium fertilizer.[150]

Before using CKD as fertilizer, however, it may be useful to treat it in some manner. For example, dry CKD is easily wind blown, and some form of binding (e.g., pelletizing) may be desirable. A Russian patent describes the preparation of granules by rolling the dust in water. A rotary unloader can be used for this purpose, after which the granules are treated with CO_2 to make them non-hygroscopic[151] and mechanically strong. Other treatment methods may be used to modify the chemistry of CKD-based fertilizer to meet specific soil and crop needs. For example, a Russian group used chlorination roasting to raise the K_2O content of kiln dust to over 20 percent.[152] Indian researchers developed a method to recover about 16.5 kilograms of potassium sulfate per metric ton (15 kilograms per ton) of coarse CKD. The recovered potash salts reportedly were pure enough to be used as fertilizer for crops such as potatoes and tobacco.[153] Similarly, the potassium sulfate recovered by the Dragon Products recovery scrubber (described in Section 8.1.3) is also reportedly pure enough for use as fertilizer.[154] Dragon Products currently has an agreement with a wholesaler to purchase the by-product.

In addition to pretreating CKD, it may also be worthwhile to blend CKD with other fertilizer ingredients. For example, the magnesium content in CKD must be supplemented from

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[145] Anonymous, 1981. *CKD Use as Lime-Potash Fertilizer*. Farm Chemicals. April.

[146] *Ibid*.

[147] Mettauer, H. and A.P. Conesa, 1981. *Agronomic Value of Residual Cement Dust*. Comptes Rendus des Seances de l'Academie d'Agriculture de France. Volume 67, Number 9. pp. 772-781.

[148] Davis, T.A., *et al.*, 1975, *op. cit*.

[149] *Ibid*.

[150] Kulich, J. and A. Ragas, 1973. *Furnace Dusts from Cement Works as a Source of Available Nutrients*. Pol'nohospodarstvo. Volume 19, Number 2. pp. 113-121.

[151] Hygroscopic materials readily take up and retain moisture.

[152] Davis, T.A., *et al.*, 1975, *op. cit*.

[153] Chari, N.R. and D.K. Sahu, 1980. *Studies on the Feasibility of Recovery of Potassium Salts from CKD*. Fertilizer Technology. Volume 17. pp. 69-70.

[154] Anonymous, 1991. *Chloride-free Potash Fertilizer from Waste SO_2 and CKD*. Phosphorus and Potassium. July-August. p. 48.

another source to achieve the required magnesium to calcium ratio for plant growth.[155,156] Other examples are highlighted below.

- A Russian patent describes a process in which kiln dust is mixed with nitric acid-phosphate extract to yield an N-P-K fertilizer.[157]

- French researchers have suggested that CKD mixed with distillery sludge may yield a material having a beneficial effect on crop yield and plant composition.[158]

- A Canadian investigation found that CKD could enrich a slurry of swine manure by increasing the levels of extractable calcium and potassium. The CKD mixture also reduced odor levels.[159]

- Researchers at Penn State University have suggested that CKD could be used to produce a lime-potash fertilizer containing 35 percent calcium oxide, six percent magnesium oxide, five percent potash, and four percent sulfur. With adequate quality control, the product was projected to be worth $33 to $39 per metric ton ($30 to $35 per ton) as fertilizer.[160]

Use of CKD as a fertilizer may be of benefit to the physical characteristics of the soil as well. A French study analyzed the effects of CKD on soil structure and infiltration and its value as an amendment and fertilizer for rye grass. Based on laboratory, pot, and field experiments, the study concluded that CKD could be a useful fertilizer and soil amendment. The study documented no heavy metal toxicity to plants at normal application rates and suggested the possible use of CKD as a replacement for gypsum in the treatment of saline soils.[161]

Although there has been a considerable amount of research conducted on CKD use as a fertilizer, existing applications of CKD for this purpose have been mostly anecdotal, and there is only limited evidence that commercial CKD use as a fertilizer is growing significantly. In addition, the Soil Conservation Service (SCS), an authority on agricultural soils, is not conducting any research on CKD.[162] Nonetheless, N-Viro Energy Systems claims that N-Viro Soil has resulted in substantial savings (more than $42 per acre) to farmers by reducing chemical fertilizer costs and by increasing yields on crops such as soybeans, corn, and alfalfa.[163] In 1990, an Iowa farmer reported successful use of sewage sludge and CKD as

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[155] CKD is high in calcium, but contains relatively little magnesium.

[156] Personal communication with Hillary Inyang, Professor, University of Wisconsin, November 16, 1992.

[157] Davis, T.A., *et al.*, 1975, *op. cit*.

[158] Mettauer, H. and A.P. Conesa, 1981, *op. cit*.

[159] Barrington, S.F. and A.F. MacKenzie, 1989. *Enrichment of Swine Manures through CKD Incorporation*. Biological Wastes. Volume 29, Number 1. pp. 1-10.

[160] Anonymous, 1981. *CKD Use as Lime-Potash Fertilizer*. Farm Chemicals. April.

[161] Mettauer, H. and A.P. Conesa, 1981, *op. cit*.

[162] Personal communication with Marc Saffley, Soil Conservation Service (SCS), November 18, 1992.

[163] Anonymous, 1992. *N-Viro Achieves Record Year*. PR Newswire. February 19.

fertilizer as an alternative to conventional agricultural chemicals.[164] As discussed previously, Dragon Products expects to market one of its CKD recovery scrubber by-products as a potassium sulfate (potash) fertilizer.[165] However, the amount of potash recovered from CKD for fertilizer applications is currently insignificant in comparison to production from traditional sources.[166]

Liming Agent

As mentioned briefly above, CKD has significant potential as a liming agent. However, the effectiveness of CKD relative to agricultural lime is a subject of some dispute. According to one source, CKD performed as well as lime in raising pH on a weight basis in tests on certain soil types. However, in other tests, it took one and a half times as much CKD as lime to achieve equivalent results.[167] Research at the USDA station in Beltsville, Maryland, found that CKD had about 80 percent of the soil neutralizing capacity of lime and about the same liming qualities as pulverized limestone.[168] Studies in Latvia showed that kiln dust could fully replace lime to treat acidic soils to grow sugar beets or corn, and the dust could partially replace lime for growing potatoes and rye.[169] An Australian study found that CKD was effective in neutralizing acid soils, and suggested that if given a choice of limestone alternatives, the selection should be based on the relative costs of the purchase, transport, and application of the various materials.[170]

Based on responses to the 1991 PCA Survey and §3007 requests, use of CKD as a liming agent accounted for 5.6 percent of the CKD that went off site for beneficial use, and less than 0.5 percent of the gross CKD generated in 1990. Other documentation reports that CKD was being marketed and used as an agricultural lime on a regional basis in New York in the mid-eighties.[171,172] It is not clear what limitations or benefits were encountered from this activity.

8.2.5 Livestock Feed Ingredient

The alkaline properties of CKD have given rise to strong interest in the past in using CKD as a feed ingredient in livestock diets. In performing research on this application, however, the presence and effects of various trace metals, such as arsenic, barium, cadmium,

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164 Looker, D., 1990. *Boone Couple Adds Fuel to Sustainable Ag Debate*. Des Moines Register. January 10. Volume 141, number 171. p. 1A+.

165 Anonymous, 1991. *Chloride-free Potash Fertilizer from Waste SO_2 and CKD*. Phosphorus and Potassium. July-August. p. 48.

166 Anonymous, 1991. *Potash Mining in Alsace, France*. Phosphorus and Potassium. September-October. p. 21.

167 Anonymous, 1980. *Supplementing Ruminant Feeds with CKD Improves Livestock Performance, According to Agriculture Canada*. Feedstuffs. June 2. p. 38.

168 Davis, T.A., *et al.*, 1975, *op. cit.*

169 *Ibid*.

170 Dann, P.R., B.S. Dear, and R.B. Cunningham, 1989. *Comparison of Sewage Ash, Crushed Limestone, and CKD as Ameliorants for Acid Soils*. Australian Journal of Experimental Agriculture. Volume 29. pp. 541-549.

171 Naylor, L.M., J.C. Dagneau, and I.J. Kugelman, 1985. *CKD - A Resource Too Valuable to Waste?* Proceedings of the Seventeenth Mid-Atlantic Industrial Waste Conference on Industrial and Hazardous Wastes. June 23. pp. 353-366.

172 Naylor, L.M., E.A. Seme, and T.J. Gallagher, 1986. *Using Industrial Wastes in Agriculture*. BioCycle. February. pp. 28-30.

chromium, lead, mercury, and selenium, have been regarded with concern.[173] Although international interest in the use of CKD for livestock feed has been relatively high, as of the mid-eighties, U.S. regulatory agencies forbade the use of CKD in the diets of animals destined for human consumption.[174,175] Under interstate commerce regulations, the FDA has not approved the use of CKD as a livestock feed ingredient. If the meat from an animal fed with CKD does not leave the state the animal lived in, however, this would not violate FDA requirements. Therefore, it is possible for some animals to be fed CKD, but the FDA is not aware of this occurring.[176] According to an FDA representative, no approval requests are currently being processed for CKD use as an animal feed, though occasional inquiries are received.[177]

Experiments conducted on steers and lambs in the late seventies revealed that diets containing 3.5 percent CKD, with and without supplemental protein, provided better growth results than diets without CKD. Further, carcasses from steers fed kiln dust were superior to those of other steers (e.g., they had more fat over the rib, a higher marbling score, and "graded" higher).[178] An analysis of the complete diets, in correlation with kidney and liver tissues, showed that there was no undesirable accumulation of elements such as arsenic, cadmium, lead, or selenium.[179,180] The results of the experiment were attributed to the neutralizing effect of CKD on rumen acids in the animals' gastrointestinal tracts, the presence of macro and trace mineral elements, and the possible increased mineral availability afforded by CKD.[181] Similar research has not produced findings of significantly elevated levels of heavy metals, or any cases of toxicity, in the animals studied. Further, one study concluded that the long-term feeding of CKD to steers did not elevate metal levels sufficiently to cause any real concern. According to one source, based on World Health Organization standards, meat from these steers would be of little concern in a well-balanced diet.[182] A Russian study found that CKD fed to cattle increased body weight gain and reduced the percentage of premature culling of stock.[183] Similar experiments with rats and swine during this same period showed a positive

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[173] U.S. Department of Agriculture, 1979. Letter from William E. Wheeler, Research Animal Scientist, Nutrition, to John P. Lehman, Hazardous Waste Management Division, Office of Solid Waste, U.S. EPA. February 23.

[174] Wheeler, W.E., 1981. *Variability in Response by Beef Steers to CKD in High Concentrate Diets*. Journal of Animal Science. March. Volume 52. pp. 618-627.

[175] Bush, R.S. and W.G. Nicholson, 1985. *The Effect of CKD on Tissue Accumulation of Trace Minerals in Steers*. Canadian Journal of Animal Science. June. Volume 65. pp. 429-435.

[176] Personal communication with Dr. Donna Waltz, Center for Veterinary Medicine, Animal Feeds Division, FDA, November 1992.

[177] *Ibid*.

[178] Wheeler, W.E. and R.R. Oltjen, 1979. *CKD in Complete Diets for Finishing Steers and Growing Lambs*. Journal of Animal Science. March. Volume 48. pp. 658-665.

[179] Wheeler, W.E., 1978. *CKD: A Potential Feed Ingredient for Livestock*. Cereal Foods World. Volume 23. pp. 296-297, 299, 312.

[180] Wheeler, W.E. and R.R. Oltjen, 1979, *op. cit*.

[181] *Ibid*.

[182] Bush, R.S. and W.G. Nicholson, 1985, *op. cit*.

[183] Karadzhyan, A.M., A.G. Chirkinyan, L.V. Efremova, and A.A. Evoyan, 1982. *Effect of CKD on Growth and Development of Young Cattle*. Trudy Erevanskogo Zootekhnichesko-veterinarnogo Instituta. Number 53. pp. 10-14.

growth effect like that found in cattle.[184,185] Canadian experiments showed weight gain rates of 22 percent in sheep and nine percent in cattle fed with CKD. The best results were with finishing lambs and young Holstein heifers.[186]

Researchers have also found that feed supplemented with CKD did not consistently stimulate growth of rats, mice, hamsters, and lambs.[187,188,189] Italian researchers found that while CKD had no adverse effect on the health of lambs, it also had no significant effect on rate of weight gain, feed intake, feed conversion efficiency, or carcass weight.[190] Similarly, additional studies of steers, yearling beef heifers, dairy cows, and lambs also indicated an inconsistent or nonexistent growth response to CKD.[191,192,193,194,195,196] This variability in response appeared to be the result of variability in the composition of CKD between different sources and even within the same source.[197] Other researchers agreed that the variable composition of CKD makes it somewhat unreliable as a feed additive.[198] The feed mixture fed to animals could also be a

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[184] Roginski, E.E. and W.E. Wheeler, 1978. *A Growth Effect of Georgia CKD in Rats*. Federation Proceedings. Volume 37. p. 404.

[185] Newton, G.L. and O.M. Hale, 1979. *CKD and Carboxylin as Feed Additives for Swine*. Journal of Animal Science. October. Volume 49. pp. 908-914.

[186] Anonymous, 1980. *Supplementing Ruminant Feeds with CKD Improves Livestock Performance, According to Agriculture Canada*. Feedstuffs. June 2. p. 38.

[187] Galvano, G., A. Lanza, L. Chiofalo, and M. Mal'an, 1982. *CKD as a Mineral Source in Feeding Ruminants*. World Review of Animal Production. Volume 18, Number 4. pp. 63-71.

[188] Roginski, E.E. and W.E. Wheeler, 1979. *The Response of Monogastric Species to CKD in the Diet*. Federation Proceedings. Volume 38. p. 614.

[189] Zinn, R.A., R.A. Lovell, D.R. Gill, F.N. Owens, and K.B. Poling, 1979. *Influence of CKD on Animal Performance and Nutrient Availability*. Journal of Animal Science. Volume 49. p. 422.

[190] Galvano, G., A. Lanza, L. Chiofalo, and M. Mal'an, 1982, *op. cit*.

[191] Anonymous, 1980. *Supplementing Ruminant Feeds with CKD Improves Livestock Performance, According to Agriculture Canada*. Feedstuffs. June 2. p. 38.

[192] Ward, G.M., C.A. Olds, D.D. Caveny, and G.A. Greathouse, 1979. *CKD in Finishing Lamb Diets*. Journal of Animal Science. September. Volume 49. p. 637.

[193] Noller, C.H., J.L. White, and W.E. Wheeler, 1980. *Characterization of CKDs (Fed to Animals) and Animal Response*. Journal of Dairy Science. November. Volume 63. pp. 1947-1952.

[194] Zinn, R.A., R.A. Lovell, D.R. Gill, F.N. Owens, and K.B. Poling, 1979. *op. cit*.

[195] Wheeler, W.E., 1981, *op. cit*.

[196] Felix, A., D.R. Rao, C.B. Chawan, and P.I. Ikem, 1980. *Effect of CKD on Nutrient Digestibility in Sheep*. Annual Research Report: School of Agriculture, Alabama A&M. pp. 103-109.

[197] Noller, C.H., J.L. White, and W.E. Wheeler, 1980, *op. cit*.

[198] Hogue, D.E., P.J. Van Soest, J.R. Stouffer, G.H. Earl, W.H. Gutenmann, and D.J. Lisk, 1981. *CKD as a Selenium Source in Sheep Rations*. The Cornell Veterinarian. January. Volume 71. pp. 69-75.

source of these varying results. For example, diets containing alfalfa hay appeared to be unaffected by CKD supplementation because they already had sufficient buffering capacity.[199]

Along with inconsistent results, some research has indicated potentially adverse impacts from using CKD as a livestock feed amendment. German researchers found that in instances where CKD was fed to cattle, weight increases were up to 14 percent lower than would be expected. In one case, an extremely low weight gain required a reduction of the percentage of CKD fed to the animal.[200] A study of CKD fed to rainbow trout showed no significant difference in growth rate or feed conversion. It also showed an increase in selenium concentrations in the fishes' livers, though no fish died and there were no pathological signs.[201] CKD fed to swine depressed body weight gain and apparently interfered with normal bone metabolism to the extent of causing bone lesions on the humerus.[202] CKD fed to broiler chicks caused no significant improvement in growth rate or feed utilization when fed at low levels, and caused severe rickets when fed at high levels (five to nine percent).[203]

The use of CKD as a feedstock additive in animals used for human consumption does not appear to be viable in the United States in the immediate future, despite the fact that most research has reported positive or neutral effects.

8.2.6 Lime-Alum Coagulation in Water Treatment

In water treatment, CKD can be substituted for lime in coagulation processes.[204] CKD was reportedly used in 1975 in Oregon as a partial and total replacement for lime in the preparation of alum floc to remove turbidity from water. Use of kiln dust was successful in neutralizing the water and in improving flocculation.[205] More recent examples citing the use of CKD for this purpose have not been found.

8.2.7 Construction Applications

Although CKD is not typically blended into the finished cement product at the facility, CKD has been found in some construction applications to perform well when blended with cement and aggregates to make concrete. In these instances, CKD is often blended together with other additives, such as fly ash and/or lime. The concrete made from CKD blending can be used for purposes such as road base construction. There have been a number of studies on the suitability of concrete made with CKD for this and other construction applications.

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[199] Noller, C.H., J.L. White, and W.E. Wheeler, 1980, *op. cit*.

[200] Flachowsky, G., H.J. Lohnert, G. Stubedorff, E. Flachowsky, G. Staupendahl, and A. Hennig, 1982. *The Use of Portland CKD in the Feeding of Fattening Bulls*. Archiv fur Tierernahrung. Volume 32. pp. 93-98.

[201] Rumsey, G.L., W.H. Gutenmann, and D.J. Lisk, 1981. *CKD as an Additive in the Diets of Rainbow Trout*. Progressive Fish-Culturist. Volume 43. pp. 88-90.

[202] Pond, W.G., D.A. Hill, C.L. Ferrell, and L. Krook, 1982. *Bone Lesions in Growing Swine Fed 3 Percent CKD as a Source of Calcium*. Journal of Animal Science. January. Volume 54. pp. 82-88.

[203] Veltmann, J.R. and L.S. Jensen, 1979. *Effect of Georgia CKD on Broiler Chick Performance*. Poultry Science. Volume 58. p. 1027.

[204] Eger, V.G. and O.N. Mandryka, 1984. *The Possibility of Using Bentonite Clay for Purification of Wastewaters From Apatite Processing*. Journal of Applied Chemistry of the USSR. Volume 57. pp. 2420-2422.

[205] Davis, T.A., *et al.*, 1975, *op. cit*.

Blending with Portland Cement

A large number of studies have demonstrated that CKD can successfully replace a portion of portland cement in making concrete. Various blends have been researched, using only CKD as an additive, and using CKD with other additives. According to responses to the 1991 PCA Survey and §3007 requests, about 2.7 percent of the CKD that was sold or given away in 1990 was used as a materials additive.

CKD as the Only Blending Agent

Some research shows that CKD can replace over 50 percent of prescribed portland cement for certain concrete applications. A study of concrete made with five percent CKD found that the properties of CKD concrete were almost the same as those of normal concrete mixes.[206] Additional research demonstrated that a five percent replacement of portland cement with CKD did not appreciably affect the freeze-thaw durability of cement.[207] Another study of concrete made with various proportions of CKD concluded that, while replacing cement with CKD generally increased water demand and decreased concrete strength, CKD could replace cement by up to 15 percent without causing significant strength loss.[208] Martin Marietta Corporation has submitted a patent application for concrete blocks containing 10 to 60 percent CKD. The blocks reportedly show improved compressive strength compared to blocks without CKD.[209]

Coupled with the positive results outlined above, the use of CKD as a replacement for portland cement has also been shown to have limitations. According to some studies, excessive quantities of CKD in cement (amounts vary depending on CKD composition) will decrease the strength and workability of the cement product.[210,211] CKD also tends to retard setting time.[212,213,214] The high levels of sulfate and alkali contained in certain dusts may also have an undesirable effect on concrete durability.[215] One study showed that alkali-aggregate reactivity in cement

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[206] Ramakrishnan, V., 1986. *Evaluation of Kiln Dust in Concrete*. American Concrete Institute. pp. 821-839.

[207] Ramakrishnan, V. and P. Balaguru, 1987. *Durability of Concrete Containing CKD*. American Concrete Institute. pp. 305-321.

[208] Ravindrajah, R.S., 1982. *Usage of CKD in Concrete*. International Journal of Cement Composites and Lightweight Concrete. May. Volume 4, Number 2. pp. 95-102.

[209] Martin Marietta Corporation, date unknown. *Poured, Moulded, or Pressed Concrete Blocks Contain Aggregate, Cement, and CKD*.

[210] Bhatty, M.S.Y., 1985. *Use of CKD in Blended Cements: Alkali-Aggregate Reaction Expansion*. World Cement. December. Volume 16, number 10. pp. 386, 388-390, 392.

[211] Ravindrajah, R.S., 1982, *op. cit*.

[212] Bhatty, M.S.Y., 1984. *Use of CKD in Blended Cements*. World Cement. May. Volume 15, Number 4. pp. 126-134.

[213] Ramakrishnan, V., 1986, *op. cit*.

[214] Ravindrajah, R.S., 1982, *op. cit*.

[215] Valley Forge Laboratories, Inc., 1982. *Kiln Dust-Fly Ash Systems for Highway Bases and Subbases*. U.S. Department of Transportation and U.S. Department of Energy. September.

made with CKD caused greater expansion at six months than ordinary cement.[216] In a CKD treatment (alkali removal) and use investigation, however, the U.S. Bureau of Mines concluded that concrete made from either sintered or melted CKD exhibited strength equal to or greater than ASTM standards.[217]

CKD as a Co-Blending Agent

Some of the limitations of CKD as a concrete ingredient may be overcome by incorporating additional materials, such as fly ash or slag, along with the dust. A 1980 study found that pozzolanic[218] concrete containing CKD and fly ash had the property of autogenous[219] healing and concluded that such concrete was potentially useful as road base and merited further development.[220] Subsequent studies showed that the addition of either slag or fly ash to cement-CKD blends resulted in better or similar characteristics (strength, setting time, and workability) in comparison to ordinary concrete.[221] Fly ash also reportedly acts to inhibit the expansion resulting from alkali-aggregate reactivity.[222] This effect might yield a higher alkali content in portland cement, allowing increased CKD recycling at applicable kilns if the ASTM standard were changed. Little information has been found on this topic.

Some research has moved into more commercial stages of development. For example, the U.S. Patent Office has received applications and, in some cases, issued patents for the use of various blends of CKD in concrete. Examples of patent applications include those for the following products:

- A high iron hydraulic cement manufactured from red mud and CKD by calcining them with gypsum, lime, and alumina. This composition reportedly sets rapidly, is stronger in compression than portland cement, is more tolerant to the presence of alkali oxides, and has enhanced bonding to steel reinforcement. It is also low in cost due to the use of waste materials and the lower fusion temperature used in manufacturing;[223]

- Cement containing blast furnace slag, CKD, and/or calcium carbonate, and optionally, gypsum. This composition is reportedly suitable as a partial

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[216] Bhatty, M.S.Y., 1984, *op. cit.*

[217] Wilson, R.D. and W.E. Anable, 1986, *op. cit.*

[218] A pozzolan is a material rich in silica or silica and aluminum that is chemically inert and possesses little or no value as a cementing agent, but, when in a finely divided form and in the presence of water, will react with calcium hydroxide to form compounds possessing cement-like properties. The most commonly available pozzolan in use in the United States is fly ash (Valley Forge Laboratories, 1982, p. 7).

[219] Originating or derived from a source within the same subject.

[220] Miller, C.T., D.G. Bensch, and D.C. Colony, 1980. *Use of CKD and Fly Ash in Pozzolanic Concrete Base Courses*. Transportation Research Record. pp. 36-41.

[221] Bhatty, M.S.Y., 1984, *op. cit.*

[222] Bhatty, M.S.Y., 1985, *op. cit.*

[223] Regents of the University of California, 1986. *High Iron Hydraulic Cement Manufactured from Red Mud and CKD*. PCT Patent Application Number WO--86-05773. October 9.

replacement for portland cement, is less expensive, and forms concretes with better setting times and compressive strengths;[224]

- A mixture of fly ash or pozzolan, CKD, aggregate, and water that, when compacted and reacted at ambient temperature, can be used as stabilized base material to underlie road surfacing. This composition reportedly minimizes the use of energy-intensive materials such as lime and asphalt;[225] and

- A blend of portland cement, CKD, and phosphogypsum for use in producing air-filled concrete panels.[226]

The use of CKD as a blending ingredient for concrete is apparently being actively researched and marketed. Ongoing studies of applications for CKD-blended concrete may provide new alternative uses in the future.

Use as a Road Base Material

According to the 1991 PCA Survey responses and §3007 requests, approximately 1.2 percent of the CKD used beneficially in 1990 was used for road base construction. This application of CKD has been researched since the 1970s. A study in the late seventies by the Transport and Road Research Laboratory in the United Kingdom concluded that freshly-produced CKD has little application in road making, but that well-weathered CKD could be useful as bulk fill.[227] More recently, however, research studies have demonstrated broader applications for CKD in road construction. Saudi Arabian researchers, for example, found that sand stabilized with CKD could be utilized for base materials in highway construction.[228]

CKD blending has also been investigated for use in road construction. For example, the U.S. Department of Transportation and the U.S. Department of Energy tested the effectiveness of substituting CKD for hydrated lime in lime-fly ash-aggregate road base systems. CKD was found to perform well in pozzolanic road base compositions involving some form of lime-fly ash stabilization. CKD generally yielded mixes with high resistance to freezing and thawing and some mixes developed early strength, possibly extending the normal cut-off dates for late season construction. The study found that, with few exceptions, fresh CKD worked with nearly any fly ash to produce strengths as high or higher than those observed with commercial hydrated lime and fly ash, although larger CKD quantities were required compared to normal hydrated lime to achieve the same strength. The study also found that aged CKD from stockpiles had a lower free lime content and resultant poor reactivity. Additionally, CKD from dry process plants tended to produce the highest strength concrete. Total dusts containing both fine and coarse CKD were better than separated CKD. The study concluded that, owing to its

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[224] Standard Concrete Material, Inc., 1983. *Cement Composition as Substitute for Portland Cement Containing Blast Furnace Slag, CKD, and/or Calcium Carbonate, and Optionally Gypsum*. PCT Patent Application Number WO--83-01443. April 28.

[225] Nicholson Realty, date unknown. *Cementitious-hardening Paving Base Composition Using Waste Materials*.

[226] Bryansk Technical Institute, date unknown. *Solution for Building Applications Containing Portland Cement, CKD, and Phosphogypsum*.

[227] Sherwood, P.T., L.W. Tubey, and P.G. Roe, 1977. *The Use of Waste and Low-Grade Materials in Road Construction*. Transport and Road Research Laboratory. Crowthorn, England.

[228] Baghdadi, Z.A. and M.A. Rahman, 1990. *Potential of CKD for the Stabilization of Dune Sand in Highway Construction*. Building and Environment. Volume 25, Number 4. pp. 285-289.

calcium oxide or unreacted lime content, CKD may be used in place of hydrated lime or portland cement as a pozzolanic road base material.[229]

Research has also demonstrated that some CKD blends do not perform satisfactorily. For example, a study by the Florida Institute of Phosphate Research concluded that a mixture of phosphogypsum and CKD was not useful for road construction.[230] CKD has an inherent propensity to degrade or react in place. This instability can lead to differential settlement problems. Further, CKD has no shear strength due to its fine-grained particle size. The shear strength due to cohesion alone is minute unless the dust is modified for use. The fine-grained character of CKD introduces the additional problem of erodability and sediment transport.[231]

The use of CKD as a road base material appears to have developed to a commercial stage and to be of continued interest, though quantities used for this purpose are currently small. Depending on the project, a state can specifically require the use of CKD or a contractor may request it. One explanation for the limited use of CKD as a road sub-base may be that new construction calls for flexible pavements with drainable bases. CKD, in contrast, is rigid and has a low permeability. In addition, less new sub-base construction is currently taking place, giving way to increased sub-base rehabilitation instead. Nonetheless, CKD provides an economically viable alternative to substitute products, such as fill materials and lime, because it is more economically competitive. Transportation costs can, however, add substantially to the price and ultimately drive the market for the dust.[232]

Despite the apparent economic advantages of using CKD as a road base material, the subject does not appear to have attracted much continuing attention. Neither the Department of Transportation (DOT) nor the Federal Highway Authority is funding research on the subject, nor does DOT maintain data records on the use of CKD in this manner.[233]

8.2.8 Sanitary Landfill Daily Cover

Because of the fine nature of CKD particles, the use of CKD as a landfill cover can probably only be achievable when it is blended with some other material. N-Viro Soil, for example, is used as a daily cover for a number of municipal landfills with contracts set for up to 15 years beginning in 1990. N-Viro Soil is being used for this application at the rate of 9 to 104 dry metric tons (10 to 115 dry tons) per day per landfill, depending on the landfill.[234,235]

8.2.9 Mineral Filler

According to an early source, CKD has been used as a mineral filler for bituminous paving materials and asphaltic roofing materials. It has also been suggested as a filler for plastics and for asphaltic products such as insulating board, concrete expansion strips, and

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[229] Valley Forge Laboratories, Inc., 1982, *op. cit*.

[230] May, A., J.W. Sweeney, and J.R. Cobble, 1983. *Use of Florida Phosphogypsum in Synthetic Construction Aggregate*. Florida Institute of Phosphate Research Publication Number 01-008-026.

[231] Personal communication with Hillary Inyang, Professor, University of Wisconsin, November 16, 1992.

[232] Personal communication with Mike Rafalowski, DOT-FHA, November 16, 1992.

[233] *Ibid*.

[234] N-Viro Energy Systems, 1991, pp. 9-10, *op. cit*.

[235] Personal communication with Robert Bastion, Office of Water-Wastewater Enforcement, EPA, November 1992.

sound deadening material.[236] EPA's research has not yielded more recent discussions of such applications.

8.2.10 Lightweight Aggregate

In the mid-seventies there was at least one process under development to use CKD in the manufacture of lightweight aggregate.[237] However, EPA's research has not yielded more recent discussions of this application.

8.2.11 Glass Making

Researchers have reported success in the use of CKD to make glass for which color and high chemical stability are not essential considerations. According to this finding, CKD can serve as a partial replacement for soda ash in the manufacture of green glass because it increases the rate of sulfate decomposition, the main cause of foaming in glass baths.[238] The developmental stage of this technology is uncertain, and EPA's research has not yielded more recent discussions of the use of CKD in glass making.

8.3 ON-SITE LAND DISPOSAL

Net CKD that is removed from the kiln system and not beneficially utilized is disposed, generally in landfills, piles, or ponds. In a landfill, CKD is generally disposed below grade (e.g., in mines, stopes, or quarries) and is sometimes buried between layers of earth. Piles are typically above-grade deposits of CKD. Submerged management of CKD in ponds accounts for only a small portion of on-site CKD management. As discussed in Chapter 4, responses to the 1991 PCA Survey and EPA observations during 1992 sampling activities demonstrate that the predominant CKD waste management practice at cement plants is disposal in a retired portion of the limestone quarry.

An alternative to these land disposal practices is to dispose CKD in an engineered landfill. Engineered landfills are typically constructed with environmental controls that are designed to contain wastes within the disposal unit. Monitoring of ground water and other environmental media in the vicinity of the landfill is often performed to ensure that the environmental controls are functioning properly. Daily operations are performed according to procedures that limit exposure of nearby populations to windblown dust and other potential hazards.

The remainder of this section discusses, in general terms, the design and operating practices frequently used at engineered landfills. The specifics of landfill design actually vary widely from site to site depending on numerous factors such as the intrinsic hazard of the waste; the requirements imposed by federal, state, and local regulations; the climate and hydrogeology of the site; the resource value of the underlying ground water; the proximity of nearby populations and endangered species; and the location of the site relative to sensitive environments such as floodplains, seismic impact zones, and wetlands.

Engineered landfills are designed with run-on control systems. Run-on from adjacent property can increase the amount of water percolating into the landfill and contribute to leachate formation; leachate is liquid that has percolated through the wastes and extracted dissolved or suspended materials. Run-on can be controlled through construction of diversion ditches, trench drains, and other devices. Typically, run-on control systems are designed to prevent flow onto the active portion of the landfill during the peak discharge from a 25-year storm. Well-designed landfills also have run-off control systems to prevent surface run-off from the site from

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[236] Davis, T.A., *et al.*, 1975, *op. cit.*

[237] *Ibid*.

[238] *Ibid*.

entering nearby areas and streams. Run-off control systems are typically designed to collect and control the water volume resulting from a 24-hour, 25-year storm.

Engineered landfills are equipped with components that contain and remove leachate. Liner systems are frequently installed prior to placement of wastes in landfills to prevent leachate from entering ground water. Liner systems are constructed with low-permeability soils and/or synthetic materials that are sloped to divert the leachate to underdrain pipes, which collect the leachate for treatment; these are known as leachate collection systems (LCS). Liner configurations frequently used include a single layer of compacted clay; a flexible membrane liner (FML) made of high density polyethylene (HDPE) or other material underlying a LCS; a "composite" liner system consisting of a LCS and FML overlying a two- to three-foot layer of compacted clay; and a "triple" liner system consisting of two FMLs with LCSs above and between them, overlying a layer of compacted clay. Well-designed LCSs maintain less than a 30-cm depth of leachate over the liner. All components of the liner and LCS must be constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients, physical contact with the waste and leachate, and other stresses.

Landfills equipped with leachate collection systems must also have mechanisms in place for leachate treatment and disposal. Frequently, collected leachate is recirculated back into the landfill. Alternatively, leachate may be treated on site and then discharged to a surface water body. A third alternative is to discharge the leachate to a municipal wastewater treatment plant with or without prior treatment, depending on the characteristics of the leachate and the requirements of the sewage treatment plant. Many different types of biological and physical/chemical treatment technologies are available for treating leachate prior to discharge to surface water or a wastewater treatment plant. Discharges of collected leachate and run-off to surface water must be performed in accordance with National Pollutant Discharge Elimination System (NPDES) requirements established pursuant to Section 402 of the Clean Water Act.

Ground-water monitoring is frequently conducted to detect leachate releases from landfills and evaluate the degree and significance of resultant ground-water contamination. Effective monitoring well systems must comprise a sufficient number of appropriately located wells able to yield ground-water samples that represent the quality of background ground water and the quality of ground water downgradient of the fill area. The number, spacing, and depths of monitoring wells are based on site-specific characteristics. Samples are collected periodically and analyzed for hazardous constituents or for parameters that indicate that a release has occurred. Statistical analysis of the samples is performed to help determine whether a release has occurred and the nature and extent of the contamination. Operators of some landfills also conduct monitoring of surface water, soils, and air.

If contamination is significant, corrective action is taken to clean up the environment to the extent feasible. Many different types of ground-water corrective action technologies are available, including source controls to minimize further releases (e.g., excavation of the waste, placing a low-permeability cap over the fill area); ground-water recovery wells that remove ground water from the subsurface and treat it to reduce contaminant levels; and slurry walls, which restrict ground-water flow and thereby minimize further spread of the contamination. The technical feasibility, costs, and effectiveness of these technologies vary widely from site to site.

Closure and post-closure care are important components of environmentally protective landfill management. When a landfill (or a portion of the landfill) is filled to capacity, a final cover is installed to minimize infiltration and erosion. The cover may consist simply of vegetated top soil. More sophisticated covers also contain a liner made of polyvinyl chloride (PVC) or other synthetic material underlying a drainage collection system; "composite" cover systems also include a two-foot clay layer. The cover should be designed with a permeability less than or equal to the permeability of the bottom liner system or natural subsoils to prevent ponding at the bottom of the landfill. After the landfill is closed, post-closure care is conducted for many years. Post-closure care activities typically include maintenance of the integrity of the landfill cover, operation of the LCS, and monitoring of ground water.

A wide variety of additional design and operating features are practiced at landfills, including access controls (e.g., installation of fences to prevent public exposure to hazards), the use of daily cover (covering each day's fill with soil to prevent dust from blowing), and others. The degree of latitude that a landfill owner or operator may exercise in selecting among the environmental controls discussed above depends largely on the regulatory status of the landfill. Without federal or state requirements, the need for these controls depends on the characteristics of the waste and the environmental and exposure characteristics of the waste disposal site.

8.4 SUMMARY AND FINDINGS

This chapter has presented an overview of CKD management alternatives. The length of discussion allotted for the various technologies does not necessarily reflect EPA's views on their relative merits, but instead is a function of disparities in the availability of information. Moreover, the conclusions derived from these discussions are tentative and subject to reevaluation upon receipt of new information.

Although investigators have explored numerous alternative CKD management practices, the scope of practices being utilized commercially remains limited. The perceived economics of CKD management and familiarity with existing techniques may be limiting more widespread adoption of alternatives to CKD disposal. For example, though available technologies could allow nearly 100 percent of gross CKD to be recycled to the kiln, the capital cost of adopting this practice may seem excessive for many operators, especially given the absence of strong incentives to reduce the quantities of net CKD generated. EPA has examined in detail the economic feasibility of some of these alternative management practices. This analysis is presented in Chapter 9 of this report.

Exhibits 8-4 and 8-5 (on pages 8-43 to 8-46) summarize the alternatives discussed in this Chapter for minimizing CKD removal from the kiln system and for beneficially using CKD that is removed from the system. The exhibits indicate general characteristics of each alternative in terms of technical feasibility, environmental considerations, economic considerations, and trends in use. Overall findings with respect to these factors are discussed below.

Exhibit 8-4

Summary of Alternatives for Minimization of CKD Removal from the Kiln System

ALTERNATIVE	TECHNICAL FEASIBILITY			ECONOMIC CONSIDERATIONS			ENVIRONMENTAL CONSIDERATIONS	NOTES
	DEVELOPMENTAL STAGE[a]	OPERATIONAL IMPACTS[b]	OPERATIONAL COMPLEXITY	START-UP COSTS	OPERATING COST SAVINGS[c]	NEW PRODUCTS		
Recovery Scrubbing	Pilot/ Limited Commercial	-Increased system efficiency -Versatile fuel choices	Moderate to High - However, no net increase of personnel is required	High	High - Investment payback expected in <5 yrs.	-Potassium sulfate potentially marketable as fertilizer -Distilled water	-Reportedly discharges only clean air and distilled water -Pilot plant is beginning to consume its backlog of dust previously generated -Reportedly removes 90 to 98 percent of the SO_2 in the flue gas	Reportedly improves kiln's particulate capture efficiency of CKD and unburned organics
Leaching with Water and Return to Kiln	Limited Commercial	-Sludge drying system required for dry kilns	Low	Low	Moderate	Leaching solution suitable as liquid potassium fertilizer	-Increased materials and energy efficiency -Less CKD to Disposal	-Leaching with hot water removes more alkali than leaching at ambient conditions
Fluid Bed Dust Recovery	Pilot	None Identified	High	High	High	Unusable dust may be of value as a fertilizer	-Increased materials and energy efficiency -Less CKD to Disposal -Other aspects unknown	In some cases, a binder may be required for pelletization of CKD
Leaching with KCl Solution and Return to Kiln	Theoretical/Bench	None Identified	Unknown	Unknown	Low to High	Unknown	-Increased materials and energy efficiency -Less CKD to Disposal -Other aspects unknown	Optimal leaching conditions were found at 70 to 80°C
Alkali Volatilization	Theoretical/Bench	None Identified	Unknown	Unknown	Low to High	Can yield cement product or cement additive	Unknown	Sintering is the primary method
Control of Gross CKD Generation Rates	Full Commercial	-Can decrease process stability -Can decrease product quality	Low	Low	Low	No	-Increased materials and energy efficiency -Less CKD to Disposal	-Primary control is to minimize turbulent conditions in kiln -Major process changes to reduce gross CKD would rarely be economically justifiable
Control of Raw Feed and Fuel Inputs to the Kiln	Full Commercial	Can decrease product quality	Low to Moderate	Low	Low to Moderate	No	-Increased materials and energy efficiency -Less CKD to Disposal	-Alternative raw feed sources limited -Use of alternate fuel can affect temperature profile of kiln and must be monitored -Hazardous waste fuels containing higher levels of chlorine can increase net CKD generation
Direct Return to Flame End	Full Commercial	-Can reduce flame temperature -Resuspends Dust	Low	Low	Low to High	No	-Increased materials and energy efficiency -Less CKD to Disposal	-Limited by reduced flame temperature that dust causes in burning zone -Causes continuous resuspension of dust
Direct Return to Mid-Kiln	Limited Commercial	None Identified	Low	Low	Low to High	No	-Increased materials and energy efficiency -Less CKD to Disposal -Can release fugitive dust	Difficulties can arise in mounting the sleeve

Exhibit 8-4 (continued)
Summary of Alternatives for Minimization of CKD Removal from the Kiln System

ALTERNATIVE	TECHNICAL FEASIBILITY			ECONOMIC CONSIDERATIONS			ENVIRONMENTAL CONSIDERATIONS	NOTES
	DEVELOPMENTAL STAGE[a]	OPERATIONAL IMPACTS[b]	OPERATIONAL COMPLEXITY	START-UP COSTS	OPERATING COST SAVINGS[c]	NEW PRODUCTS		
Direct Return with Raw Feed	Full Commercial	Some obstacles for wet slurry	Low	Low	Low to High	No	-Increased materials and energy efficiency -Less CKD to Disposal	Can return CKD either at kiln input or at blending stage
Pelletizing and Return to Kiln	Full Commercial	Reduced resuspension of dust	Unknown	Low	Low to High	No	-Increased materials and energy efficiency -Less CKD to Disposal	-Gives CKD necessary strength to withstand forces of being fired into flame -Avoids need for flame characteristic modification

[a] "Developmental Stage" describes the usage level at which the technology is being implemented, classified as Theoretical, Bench Scale, Pilot Scale, or in Limited Commercial or Full Commercial development.

[b] "Operational Impacts" describes effects of the technology on the kiln system or the clinker product.

[c] "Operating Cost Savings" provides a qualitative assessment of the operating costs savings likely to be realized through using a given technology, and is considered separately from start-up costs. Classes are low, moderate, and high, with many technologies ranging from low to high because savings depend upon the amount of net CKD that is returned.

Exhibit 8-5

Summary of Alternatives for Beneficial Utilization of CKD Removed from the Kiln System

ALTERNATIVE	DEVELOPMENTAL STAGE[a]	VALUE OF PRODUCT[b]	MARKET STATUS[c]			ENVIRONMENTAL CONSIDERATIONS	NOTES
			POTENTIAL DEMAND	CURRENT STATUS	APPARENT TRENDS		
Stabilization of Sewage Sludge	Full Commercial	High	High	Common	Growing	CKD may be dispersed in environment with unclear impacts	-Successfully marketed as a treatment agent under the names Stablesorb and N-Viro Soil -Municipality can save $13 per wet metric ton ($12 per wet ton) on sewage disposal
Sanitary Landfill Daily Cover	Full Commercial	High	High	Limited-Common	Growing	CKD is managed under controlled conditions	Most applications use CKD/sewage sludge blend
Stabilization of Oil Sludge	Full Commercial	Moderate	High	Common	Growing	CKD is dispersed in environment with unclear impacts	
Stabilization of Acid Wastes	Full Commercial	Moderate	High	Common	Growing	CKD is dispersed in environment with unclear impacts	
Stabilization of Miscellaneous Wastes	Full Commercial	Moderate	High	Common	Growing	CKD is dispersed in environment with unclear impacts	
Soil Stabilization	Full Commercial	Moderate	High	Common	Unknown	-CKD is dispersed in environment with unclear impacts -Helps reduce fugitive dust and erosion from soil	Decreases shifting and subsidence
Road Base	Full Commercial	Low	Moderate to High	Limited-Common	Growing	CKD is dispersed in environment with unclear impacts	Variable composition of CKD hinders reliability
Land Reclamation	Full Commercial	Low	High	Limited-Common	Unknown	CKD is dispersed in environment with unclear impacts	
Fertilizer	Full Commercial	Moderate	High	Limited-Common	Stable-Growing	-CKD is dispersed in environment with unclear impacts -Potential limitations for food chain crops	
Liming Agent	Full Commercial	Moderate	High	Common	Stable-Growing	-CKD is dispersed in environment with unclear impacts -Potential limitations for food chain crops	
Blending Agent with Portland Cement	Bench	Low - Moderate	Moderate	Limited-Common	Growing	CKD is dispersed in environment with unclear impacts	-Large percentages will decrease strength and workability, and retard setting time -Variable composition of CKD hinders reliability
Lime-Alum Coagulation in Water Treatment	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown impact on treated water	
Blending Agent with Other Materials	Bench	Low - Moderate	Moderate?	Limited-Common	Growing	CKD is dispersed in environment with unclear impacts	-Variable composition of CKD hinders reliability -Adds autogenous healing to pozzolanic concrete

Exhibit 8-5 (continued)
Summary of Alternatives for Beneficial Utilization of CKD Removed from the Kiln System

ALTERNATIVE	DEVELOPMENTAL STAGE[a]	VALUE OF PRODUCT[b]	MARKET STATUS[c]			ENVIRONMENTAL CONSIDERATIONS	NOTES
			POTENTIAL DEMAND	CURRENT STATUS	APPARENT TRENDS		
Mineral Filler	Limited Commercial	Unknown	Unknown	Unknown	Unknown	Unknown	
Lightweight Aggregate	Unknown	Unknown	Unknown	Unknown	Unknown	CKD is dispersed in environment with unclear impacts	One process under development in the mid-seventies
Glass Making	Theoretical/Bench	Unknown	Unknown	Unknown	Unknown	Unknown	Successful when color and high chemical stability are not essential
Livestock Feed Ingredient	Theoretical/Non-commercial Pilot	Unknown	Unknown	Not believed to be used in U.S.	No Growth	CKD in diets of animals destined for human consumption is not permitted in U.S.	Variable composition of CKD hinders reliability

[a] "Developmental Stage" describes the usage level at which the technology is being implemented, classified as Theoretical, Bench Scale, Pilot Scale, or in Limited Commercial or Full Commercial development.

[b] Value of product is qualitatively ranked relative to anticipated value of other beneficial uses (highly speculative).

[c] "Market Status" is comprised of three categories: Potential Demand, based on a qualitative estimate of the user market; Current Status, based on available information about current CKD demand for a given use; and Apparent Trends, based on a qualitative assessment of current demand trends.

8.4.1 Technical Feasibility

Most of the management alternatives discussed above are technically feasible to at least some degree. The differences lie in how practical these alternatives are in terms of investment requirements, expected benefits, and performance standards. Process controls that minimize gross dust generation rates and alkali levels are commonly used throughout the industry. Significant reductions in current CKD generation probably cannot be achieved through these means without compromising product quality. Although process differences can influence the amount of CKD recycled (e.g., fuel type, process type, feed inputs, etc.), the incremental benefit of initially removing less CKD from the kiln system is unlikely to induce significant and potentially costly process changes.

CKD treatment and return systems show the greatest promise for increasing the amount of CKD returned to the kiln system. These treatment systems minimize net CKD generation by removing alkalies and other contaminants and returning treated dust to the system without compromising product quality. The promising technologies in this area include recovery scrubbing, alkali leaching, and fluid bed dust recovery. Water-based alkali leaching shows the greatest promise for effective CKD treatment with minimal technological requirements. Recovery scrubbing and fluid bed dust recovery, in contrast, continue to undergo development, and require significant expertise for design, installation, and optimization.

Beneficial uses of CKD are at a further stage of development than recycling technologies. In contrast to CKD treatment and recycling technologies, all of the beneficial utilization technologies appear to be readily feasible technically (at least at the pilot scale), and may involve activities as simple as blending CKD with other materials. Nonetheless, research is required to more fully commercialize such uses, since even blending requires knowledge of appropriate mixing ratios. Incorporation of fly ash with cement reportedly reduces the negative influence of alkalies on concrete strength. Additional research should be conducted to determine whether blending fly ash with cement might allow greater alkalies in clinker, and therefore greater CKD recycling rates in the kiln system. Aside from blending, the more technically challenging beneficial uses include glass making and coagulation in water treatment.

Although many viable beneficial uses of CKD have been identified, the inherent variability of CKD, as established in Chapter 3, poses a significant limitation on its widespread use. Cement kiln operations are designed to optimize the chemical and engineering characteristics of clinker, while CKD is a byproduct for which specifications cannot be developed. Hence, depending upon its ultimate use, the dust may require testing and possibly further processing. This situation may limit the option of using CKD as a material in scenarios such as when a project planner knows little or nothing about the available CKD nearest to the project location and may be willing to use a more expensive, but more standardized material.

Strictly managed land disposal practices are technically feasible, as has been demonstrated with landfills containing many other materials. Numerous engineering firms have the capability to design all necessary environmental protection features, including leachate collection and treatment systems, liners, ground-water monitoring systems, and run-on and run-off controls. These operations tend to be extremely costly, however, a reality that may provide an incentive toward developing other management alternatives.

8.4.2 Human Health/Environmental Considerations

Direct recycling or treatment and recycling practices provide an inherent environmental benefit by minimizing the amount of net CKD that will be disposed of. These practices conserve energy and resources originally used to prepare and heat the raw feed that would otherwise become wasted CKD. Furthermore, total CKD return to the kiln system eliminates the environmental liabilities associated with land disposal.

In addition to influencing CKD generation rates, the impact of alternative practices on other process waste streams should be considered. For example, some alternatives, like recovery scrubbing, can improve kiln emissions quality. This technology also reportedly generates only distilled water and potash. In contrast, any wastewater generated from alkali leaching may warrant some concern. Water containing alkalies may be released to surface or ground waters if this material is handled improperly. Based on EPA's information, however, this system can be and has been installed in a way that is environmentally protective. Further investigation of alkali leaching wastewater disposal may be warranted before the impacts of this technology can be fully assessed.

The environmental implications for beneficially using CKD are uncertain. The nature of most alternatives for beneficial utilization of CKD is to disperse it in some manner into the environment. CKD managed in this manner will generally be exposed to climatic influences such as precipitation and wind. Some alternatives, however, occur in controlled conditions, such as those in which CKD is blended with sewage sludge and used as a municipal landfill daily cover. Alternatives that involve contact with human food chain products, such as fertilizer production and livestock feed, may require more careful consideration. When appropriate, however, the use of CKD may reduce the demand for traditional materials (e.g., limestone) that would have to be mined at some environmental cost. This holds true for uses such as road base construction, soil stabilization, and waste stabilization.

CKD management in land disposal units represents wasted quantities of mined and milled raw materials. As documented in Chapter 6, CKD disposal in quarries may not adequately protect human health and the environment. One option is disposal in strictly managed landfills, which would significantly reduce threats to human health and the environment.

8.4.3 Economic Feasibility

Although the start-up costs of many of the CKD recycling technologies discussed in this chapter are low to moderate, inducing significant changes in the CKD management practices at cement facilities may require time and successful demonstration projects. The least capital-intensive CKD treatment technology appears to be water-based alkali leaching. Leaching systems can be installed with minor start-up and maintenance costs, especially as applied to wet process kilns. This technology may also generate marketable by-product(s). Recovery scrubbing and fluid bed dust recovery also show market potential. In particular, recovery scrubbing appears to show the greatest potential for adaptability and effectiveness. Notwithstanding the high start-up costs associated with these technologies, net benefits can be realized within a few years. Each of these technologies provides the economic incentives of increased product yield, and reduced resource losses to disposed CKD.

The economic incentives to sell CKD for beneficial utilization appear to be moderate but growing. In particular, uses such as stabilization of municipal sewage treatment sludge could prove to be in high demand. Municipalities will reportedly pay over $11 per metric ton ($10 per ton) for CKD as a new treatment alternative or as an alternative to lime. Not only does selling CKD for beneficial use allow operators to use the material rather than simply disposing of it, but kiln operators can realize significant revenues from such activities. For example, one facility (Ash Grove Cement) reportedly sells its dust at $11 to $22 per metric ton, a figure that may be considered full profit since the material would otherwise be disposed. Cement product, in contrast, is typically sold with a profit of about $5.50 per metric ton.[239] Regardless of the price at which CKD might be sold for such uses, the fact that operators can receive income makes it highly feasible economically. Additionally, CKD is significantly less expensive to users than most or all alternative materials. However, this savings can be lost in transport costs if the distance between the user and the cement plant is too great.

The increased costs of more strict land disposal practices would represent a significant liability to all plants disposing CKD. Implementation of Subtitle C requirements would result in costs that might make a number of CKD treatment technologies economically viable. Even eventual Subtitle D requirements, though less onerous than Subtitle C requirements, could impose a significant economic burden on operations that currently dispose their CKD.

[239] Personal communication with Hans Steuch, Ash Grove West, December 9, 1992.

8.4.4 Current Extent of Use and Trends

Currently, CKD management incentives appear to be diverging in two directions, with both recycling and beneficial use offering attractive prospects. On one hand, operators want to minimize CKD removal from the kiln to conserve resources and energy lost to a waste material, and to minimize operating costs for CKD waste management units. Considering the necessary investments in capital and labor, however, the prospect of avoided costs associated with most of the technologies to minimize CKD removal from the kiln appears to hold little appeal at present.

In contrast, the beneficial use of CKD as a marketable product appears to be growing, such that an operator might find positive incentives to remove CKD from the kiln system and sell it, thereby avoiding a costly recycling system. If EPA finds that CKD does not warrant hazardous waste regulation, many tentative markets for beneficial utilization of CKD may develop more fully to create a significant increased demand for and price of CKD. Nonetheless, several factors could increase incentives to minimize removal of CKD from the kiln. These include stricter CKD management regulations, increased fuel and feed costs, and the development of more economical recycling technologies. To minimize resource losses through disposal, and to minimize the use of CKD in beneficial areas of unknown environmental impact, EPA believes that the first CKD management objective should be to economically recycle as much CKD to the kiln as possible without compromising the quality of the clinker product.

In general, some of the most promising technologies for minimization of CKD removal from the kiln system appear to be recovery scrubbing, alkali leaching, and fluidized bed recovery. These technologies utilize all or nearly all of the CKD generated, may produce one or more marketable products, and provide a return on the invested capital.

Among the beneficial uses, stabilization of municipal sewage sludge appears to have a great deal of potential as a means of beneficially utilizing CKD, particularly as a daily municipal landfill cover, where the location of CKD use and final disposition is carefully controlled. EPA does not believe that widespread agricultural use of CKD for producing crops that are consumed by humans should be practiced without full characterization of the CKD from each source. Caution should also be exercised in using CKD as a livestock feed supplement. Other potentially useful applications of CKD include waste stabilization, soil stabilization, soil amendment (liming agent), road base construction, and blending with portland cement to make miscellaneous cement-based construction products.

If EPA determines that Subtitle C regulation of CKD is warranted, the significant potential cost of complying with Subtitle C land disposal requirements may increase the marketability of many recycling technologies. Subtitle D requirements, if implemented and enforced at the state level, could also increase the economic viability of CKD recycling technologies, which would result in less land disposal of CKD and less wastage of raw material. Requirements under these regulatory alternatives are described in detail in Chapter 9 of this report.

CHAPTER EIGHT

ALTERNATIVE CKD MANAGEMENT PRACTICES AND POTENTIAL UTILIZATION

8.0 OVERVIEW 1

8.1 MINIMIZATION OF CKD REMOVAL FROM THE KILN SYSTEM 2

8.1.1 Control of CKD Generation Rates 2

8.1.2 Direct Return of CKD to the Kiln 3

Return to Flame End 5

Return with Raw Feed 5

8.1.3 Treatment and Return of CKD to the Kiln 6

Pelletizing 6

Leaching with Water 6

Leaching with a Potassium Chloride Solution 8

Alkali Volatilization 8

Recovery Scrubbing 9

Fluid Bed Dust Recovery 13

8.2 BENEFICIAL USE OF REMOVED CKD 16

8.2.1 Stabilization of Sludges, Wastes, and Contaminated Soils 17

Sewage Sludge 17

Oil Sludge 21

Acid Waste 22

Miscellaneous Wastes and Contaminated Soils 23

8.2.2 Soil Stabilization 24

8.2.3 Land Reclamation 24

8.2.4 Agricultural Applications 25
Fertilizer 25
Liming Agent 28
8.2.5 Livestock Feed Ingredient 28
8.2.6 Lime-Alum Coagulation in Water Treatment 31
8.2.7 Construction Applications 31
Blending with Portland Cement 32
CKD as the Only Blending Agent 32
CKD as a Co-Blending Agent 33
Use as a Road Base Material 34
8.2.8 Sanitary Landfill Daily Cover 35
8.2.9 Mineral Filler 36
8.2.10 Lightweight Aggregate 36
8.2.11 Glass Making 36
8.3 ON-SITE LAND DISPOSAL 36
8.4 SUMMARY AND FINDINGS 38
8.4.1 Technical Feasibility 43
8.4.2 Human Health/Environmental Considerations 44
8.4.3 Economic Feasibility 44
8.4.4 Current Extent of Use and Trends 45

LIST OF EXHIBITS

Exhibit 8-1 **Flow Chart of Gross CKD Management Pathways** 1

Exhibit 8-2 **Process Flow Diagram of Recovery Scrubber** 10

Exhibit 8-3 **Process Flow Diagram of Fluid Bed Dust Recovery Process** 15

Exhibit 8-4 **Summary of Alternatives for Minimization of CKD Removal from the Kiln System** 39

Exhibit 8-5 **Summary of Alternatives for Beneficial Utilization of CKD Removed from the Kiln System** 41